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Rural Water Supply in China

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Rural Water Supply in China

Contents

Foreword

China has made substantial progress toward meeting the basic water supply and sanitation needs of its vast population. Integration of health care and community involvement with water supply and sanitation delivery has been an important element of these efforts. The pragmatic approach of the Chinese led to the publication of a number of simple didactic manuals on water supply that have been widely distributed throughout the country. These manuals are the primary source of information available in China's rural areas on water supply techniques.

This translation is a composite of five of these manuals: *Potable Water Supply in Rural Areas* (Public Health and Epidemic Prevention Station, Hebei Province. 1976. People's Health Press); *Waterworks Design and Construction for Rural Areas* (Shanghai Academy of City Planning and Engineering. 1978. Chinese Building Industry Press); *Digging and Repairing Wells* (Design Department of the Beijing Hydraulic Power Station. 1972); *Well Repair and Damage Prevention* (Hydraulic Power Ministry. 1975); and *Quality Standards for Domestic and Potable Water Supplies* (Ministry of Health. 1976. Chinese Building Industry Press).

The original translation from Chinese was carried out by Lee Thim Loy, engineering consultant, Malaysia, and Peter Phoon of the Civil Engineering Department of Ohio State University. The manuals were obtained during visits to China by Ariane van Buren, International Institute for Environment and Development, and Geoffrey Read, UNDP Global Project GLO/78/006 Technical Advisory Group. The latter's visit was supported by the British Filtration Society. Ariane van Buren undertook editorial rewriting and assembly of the book. Final editing was by Amy Chouinard, graphics by Wendy Moriarty, technical editing by Geoffrey Read and Michael McGarry.

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Chapter 1

Potable Water

Water and Health

Water is essential for life; not only is it required for consumption, bringing with it micronutrients such as iron, and fluoride, but also it is required for personal hygiene. Clean, potable water is needed as drinking water and for washing, bathing, laundering, dish washing, and general cleaning. Water that has been contaminated by disease-causing organisms can transmit disease.

Numerous investigators have illustrated that bacterial and viral diseases can be spread through use of contaminated water. This is a result of pathogenic bacteria and viruses originating from fecal contamination of water sources whether it be through excreta being washed into rivers, seeping into groundwater, use of excreta as fertilizer in agriculture, or improper methods of washing night-soil buckets. Infectious diseases transmitted through water are termed water-carried diseases. Once contaminated, a water source can infect all drawers of water from that source. Consequently, an epidemic of the water-carried disease may occur within a relatively short time, affecting not only public health but also production. Water or food that has become contaminated by pathogens may spread bacterial diseases, including typhoid, cholera, childhood diarrhea, and other gastrointestinal infections; viral diseases, such as infectious hepatitis, infantile paralysis, and infectious conjunctivitis; and parasitic diseases, like schistosomiasis, amebiasis, and giardiasis.

Where rivers, ponds, and shallow groundwater are the major sources of water supply as in southern China, pathogens are introduced into the water by infected persons using the water source for washing or defecation. Of all diseases affecting rural populations, those that are water-related are the most important. An outbreak of water-borne disease is evident when a cluster of cases suddenly appears, especially of persons using a common water source. Improving the quality of drinking water, disinfecting it, and abstaining from drinking untreated water are essential in prevention of water-carried diseases.

Lack or excess of certain trace elements in water causes endemic diseases that are not infectious but are widespread in areas where the water is affected; the most common endemic afflictions due to water quality are fluorosis and goitre. Chemical poisoning does not occur naturally except in areas where trace elements are excessive. People may be poisoned by water that has been polluted by human activities, especially those that produce industrial waste such as mercury, cadmium, chromium, arsenic, and organic phosphates. At present, industrial development in China is increasing; wastewater and solid wastes are augmenting other forms of water pollution. Preventing industrial pollution is essential for protection of water supplies in both urban and rural areas.

Water Quality Criteria

Maintaining adequate water quality is essential for protection of the public health. Physical characteristics of water quality can be measured with laboratory equipment or can be assessed by sight, smell, and taste. Turbidity is cloudiness caused by soil, sand, organic matter, and mineral salts in the water. Where water is contaminated by soil, sand, industrial wastewater, domestic wastewater, or suspended solids, its turbidity will be high. Unpolluted water has no colour; brown is indicative of decomposing organic matter; a dark-yellow may be caused by iron or manganese. Colour in water normally indicates some kind of contamination.

Unpolluted water is odourless so that any smell normally indicates contamination. For example, water polluted by excreta emits characteristic odours. Where industrial pollution occurs, chemical odours such as those of petroleum or benzene will be emitted. Similarly where water has a taste, it contains extraneous chemicals. High concentrations of chlorides cause a salty taste, magnesium sulfate a bitter taste, and calcium sulfate an astringent effect. Water temperatures

remain relatively constant within any season. Sudden rises in temperature indicate industrial waste discharges and are therefore very significant in identification of water pollution.

Table 1 presents water-quality standards for domestic and potable water supplies in China.

Good water does not contain chemicals in harmful quantities. The concentrations of chemicals in water are an important indicator of water quality. Also, natural water is slightly basic, with a pH ranging from 7.2 to 8.6. If water is contaminated by acidic or alkaline pollutants, its pH will change accordingly. Overly acidic or alkaline water will affect people and will damage crops irrigated with it.

Dissolved solids in the water can be detected as precipitates after evaporation. The quantity of dissolved solids depends largely on the amount of dissolved minerals that are in the water. The maximum amount of dissolved solids acceptable in potable water is 1000 mg/l.

The hardness of water indicates its calcium and magnesium salts content. The terms "hard water" and "soft water" are used to describe high or low hardness. People can get used to the hardness of water with no serious health effects; however,

Table 1. Water quality standards for domestic and potable water supplies.[a]

Parameter	Limit
Physical property	
Colour	Not more than 15° and not visually offensive
Turbidity	Not more than 5°
Tastes and odours	Not offensive
Visible solids	None
Chemical property	
pH	6.5–8.5
Hardness (CaO)	Not more than 250 mg/l
Iron	Not more than 0.3 mg/l
Manganese	Not more than 0.1 mg/l
Copper	Not more than 1.0 mg/l
Zinc	Not more than 1.0 mg/l
Volatile carbolic	Not more than 0.002 mg/l
Anionic detergent	Not more than 0.3 mg/l
Toxicological content	
Fluoride	Not more than 10 mg/l; recommended 0.5–1.0 mg/l
Cyanide	Not more than 0.05 mg/l
Arsenic	Not more than 0.04 mg/l
Selenium	Not more than 0.01 mg/l
Mercury	Not more than 0.001 mg/l
Cadmium	Not more than 0.01 mg/l
Chromium (hexacovalent)	Not more than 0.05 mg/l
Lead	Not more than 0.1 mg/l
Bacteriological content	
Total colony count	Not more than 100/ml
Coliform	Not more than 3/ml
Residual chlorine	After treatment, not less than 0.3 mg/l for the next 30 minutes. In piped supply systems, concentration at the end of the network should not be less than 0.05 mg/l.

Source: Ministry of Health, People's Republic of China, 1 December 1976.

[a]Quality of private (small) water systems should comply with the toxicological limits of these standards. If the qualities of other items cannot be adequately met, the responsible authority should start a mass campaign of sanitation to improve the public health environment, adequate measures should be adopted for water treatment, and the quality of the supply should be continually improved.

Editor's note: These standards are drawn from a separate document (TJ20-76) approved by the Ministry of Health and the Basic Construction Committee and published by the Chinese Building Industry Press, Beijing. The document is translated and presented in Appendix 4. The degree to which they are enforced throughout China is not known. The Chinese Health Ministry's water quality standards reflect the difficulties in maintaining an effective surveillance system in rural areas and China's level of industrial development. China's pragmatic approach is illustrated in its standards for bacterial contamination. They are far less stringent than Canada's water quality criteria guidelines. China does not include pesticides, radionuclides, nitrilotriacetic acid, or trihalomethanes — a reflection of the complexity of analysis needed for these and the degree to which the Chinese see them as priorities.

people accustomed to soft water who are suddenly given hard water to drink get stomach troubles and, shortly thereafter, indigestion or diarrhea. This is a common complaint in persons traveling in a new area, not acclimatized to the water. Also, hard water may change the taste of food and tea; increase the amount of soap required for washing; or damage skin, especially delicate facial skin. Overly soft water also has effects; for example, research in recent years has found that use of soft water is linked with prevalence of vascular diseases.

Chloride is an indication of the salinity of water. Salinity is caused by several compounds, although sodium chloride (ordinary salt) is the most common. The amount of chloride in natural water depends on the geology of a region. Coastal regions usually have water with high chloride concentrations, whereas concentrations are usually low in mountainous areas. However, the chloride content within one source in a particular area is usually quite consistent. An abnormal increase in chlorides suggests that the water is contaminated by human or animal excreta, domestic wastewater, or industrial chloride-containing wastewater. A high chloride content makes the water not only salty to taste but also unpleasant to use. Furthermore, it affects secretion of gastric juices and, eventually, digestion.

Like chloride, sulfate is normally present in water, and the amount depends on the geology of the area. Some sulfates, such as magnesium sulfate and sodium sulfate, cause diarrhea; therefore their concentrations must be kept low.

Iron is an essential trace element for the human body. However, at high concentrations, it gives water a bad taste and a reddish colour. It also is aesthetically undesirable because it colours cloth and turns tea and rice black. Copper is another essential trace element for humans. Natural water contains very little copper. High concentrations in drinking water produce an abnormal, generally unacceptable, taste, and excessive accumulation of copper in humans causes chronic poisoning.

Drinking water is a person's major natural source of iodine. Iodine is necessary for the production of thyroxine in the thyroid gland, and lack of it is the main cause of goitres. People need 120 μg of iodine every day to ensure proper physiologic functioning. Where iodine in water is less than 10 mg/l for a long time, people are likely to suffer from goitre. High iodine content is an important criterion in the selection of a water source and is a major factor in goitre prevention. Fluoride is essential for human bones and teeth formation and is found in small amounts in teeth, bones, and hair. Evidence shows that in areas where the fluoride in water is less than 0.5 mg/l, the occurrence of tooth decay is more frequent. Most sources contain some fluoride, and, in fact, many contain too much, causing damage to normal teeth and bone growth. Teeth become brittle, and their crowns may break off where the fluoride concentration is higher than 1.5 mg/l. With concentrations higher than 4 mg/l, chronic poisoning occurs, bone structure is seriously damaged, and bones become brittle. It is desirable to determine the fluoride content carefully in water that is for human consumption.

The many harmful substances that frequently pollute drinking water are divided into two major categories: organic matter containing nitrogen and carbon, such as human, animal excreta and decayed animal, plant matter; and chemical waste from industry. Due to the development of industry in China, discharges of industrial wastewater, solid wastes, and air pollutants are on the increase. In some countries such pollution has become a serious problem, but through the policy of "prevention first," the Chinese are trying to control pollution from the start and have made significant achievements.

The major sources of nitrogen compounds in water are animal excreta and decaying animal bodies. Nitrogen compounds include protein, nitrate, nitrite, and ammonium salts; they are the products of protein decomposition. The presence of various nitrogen compounds and their levels of concentration are good indicators of direct or indirect contamination by excreta.

When water contains proteins and organic nitrogen compounds, but no ammonia, it is freshly contaminated and has not yet reached the stages of ammonification and nitrification. However, if ammonia, nitrites, and nitrates are present, the water is being continually contaminated. Water that contains only nitrites and nitrates may have been contaminated previously and is reaching recovery. High nitrite and nitrate concentrations in water may also indicate that the water has flowed over areas with high nitrate contents. Under these circumstances, part of the nitrate may be oxidized to nitrite. Careful investigation and surveys are needed to determine water quality if nitrogen compounds are being used as indicators. Furthermore, nitrite is harmful to human beings. In high concentrations, it combines with the erythrocytes in blood and impedes the transmission of oxygen. In general, the maximum acceptable concentration of nitrate and nitrite in water is 10 mg/l.

Dissolved oxygen is an important criterion for the identification of organic contamination. Surface water that is exposed to air has considerable oxygen dissolved in it, but groundwater has only

small amounts. If the water is contaminated, its dissolved-oxygen content is low, and sometimes even exhausted, because of the oxygen consumption of microorganisms and the oxidation of pollutants.

There are numerous harmful substances in industrial wastewater and solid wastes, for example: phenols, cyanide, arsenic, mercury, chromium, cadmium, lead, toluene, aldehyde, petroleum, tar, sulfides, organic phosphorus, and chlorinated hydrocarbons. Normally, the most harmful and common contaminants are phenols, cyanide, arsenic, mercury, and chromium, which are found in the wastes of many industries, including coking, oil refining, chemical manufacturing, plating, and organics synthesis. Industrial waste can be widespread and can easily pollute surface water sources, such as rivers and lakes. Because such pollution can eventually lead to the poisoning of people and animals, its early detection is essential.

Phenols are widely used in coking, petroleum, paper, synthetic resin, and other industries, from which they can contaminate drinking water. Not only do these wastes smell unpleasant, but they react with chlorine used in water purification and produce a more pungent odour. The phenolchlorate produced by the reaction makes the water completely unacceptable for drinking. Water that contains phenols can create chronic health problems, e.g., anemia, headaches, dizziness, and other illnesses. In China, the maximum acceptable concentration of phenol in waste discharges is 0.5 mg/l, and surface water should not contain more phenol than 0.01 mg/l.

Cyanide is a highly poisonous substance that causes cells to lose their ability to dehydrogenate and oxidate; it can also affect internal respiratory functioning and cause serious poisoning. Arsenic is a trace substance in nature and harmless within its natural range of concentrations; however, industrial discharges often include arsenic levels that are poisonous. The arsenic affects the nervous and digestive systems and causes vascular problems. Mercury is another highly poisonous substance that is damaging to the nervous system and can cause fetal poisoning. The maximum acceptable concentration of mercury in surface water is 0.005 mg/l. Chromium is also poisonous; it is widely used in plating, printing, dyeing, and hide-processing industries and is discharged in their wastewaters. When a body of water is contaminated by chromates, it becomes yellow and unacceptable for drinking. High intake of chromium affects normal oxidation and may cause anemia. The maximum acceptable amount in surface water in China is 0.1 mg/l.

Polluted water is an important medium for the transmission of infectious diseases, especially intestinal diseases. Understanding the role of water will help prevent the spread of those diseases. The following are criteria that indicate the pathogen content of water:

- Total bacterial count is the number of bacteria in a litre of water as determined under certain laboratory conditions. Clean water does not usually contain more than 100 bacteria/ml (24 hours incubation at 37 °C). In contrast, polluted water, such as that contaminated by excreta, may contain more than several hundred thousand per millilitre. The numbers of bacteria in water are therefore a good indication of its quality. There are two basic types of bacteria — pathogenic (disease-causing) and nonpathogenic. It is difficult to isolate and enumerate the pathogenic ones, but a high total count suggests the presence of pathogens. Thus, an estimation of the total bacterial count in the water gives a basic indication of the danger of spreading infectious diseases. The total bacterial count is a principal criterion for water quality in China; the maximum acceptable total colony count is 100 bacteria/ml.
- The *Escherichia coli* or coliform index is defined as the number of *E. coli* in a litre of water as determined under certain laboratory conditions. An estimate of *E. coli* densities can determine the direct or indirect contamination from excreta and the possibility of other excreta-related pathogens being present. Coliform organisms do not usually cause disease. However, pathogenic organisms coexist with them in small numbers and are difficult to isolate. Therefore, the enumeration of coliform organisms is an important epidemiologic tool.

Coliform organisms normally exist in the intestinal tract and, when discharged into water, are more resilient than other pathogens. A low coliform count in water suggests the absence of intestinal pathogens; high coliform count indicates that the water was recently contaminated by excreta, the existence of intestinal pathogens is likely, and the water is unsafe.

Testing water quality is relatively complicated, but if there is any doubt concerning the quality, samples should be taken immediately and brought to the public health authorities.

Water Quality Control

Prior to liberation, the people of China lacked even adequate food and clothing; it was pointless to promote sanitation. Lack of water and sanitation was an acute problem, water-related diseases were endemic in the population, and mortality among the rural people due to communicable

diseases was very high. Since that time and especially as a result of the increasing numbers of barefoot doctors, there has been a continuing improvement in rural health. Water-supply protection and quality maintenance have become the responsibility of the barefoot doctors. Their duties include:

- Educating the people in water quality control: explaining the importance of clean water and counteracting illiteracy, superstition, and poor health practices. Following the policy of emphasizing prevention, barefoot doctors stress the interrelationship of health, production, and sanitation; disinfection and water supply improvement; communal action in guaranteeing the quality of the water supply;
- Providing advice in selection of the best source of water: it is their responsibility to conduct initial surveys of alternative sources including gathering hydrologic and geologic data, information on sanitary conditions in the surrounding areas, and analyses of soil and water quality;
- Improving the drinking water supply by protecting and treating the water using methods discussed in chapter 4; and
- Conducting drinking-water surveys as an essential step in maintaining the quality of the water.

Water Source Investigations

Potable water investigation for rural areas includes monitoring, site observation, community meetings and participation, consultations with old peasants in the area with experience of local problems, and laboratory examination.

The investigations for a well should cover the topography of the site, the location, the well life, the number of users, the maximum service radius, and the seasonal volume. A knowledge of all these items is essential in rural water management.

In northern China the main source of supply is groundwater; in southern China it is surface water. A stone-built well in northern China can have a life of about 250 years. If its age is more than 300 years, the foundation and the sealing material may be damaged and the water quality subsequently affected. Old wells should therefore be carefully maintained.

The maximum service radius is defined as the maximum distance between the well and any one of the users. This should be considered not only for the convenience of the users but also for water-quality hygiene. Investigations have indicated that the total bacterial count in water supplies increases with the distance between the well and household. The service radius of a well should be no greater than 300–400 m. It is uneconomic to have the service radius too small because of the costs in construction.

The number of users should be carefully estimated. If a well serves too many people, the water will be too rapidly withdrawn; sand and other settled materials will be disturbed; and the turbidity, total bacterial count, and coliform count will be increased.

A good well should have a solid foundation, an impervious apron, platform, lip, and cover. It has been proved that the structure of the well has an important effect on the water quality. The structure and the materials used for a well should therefore be essential items of detailed investigation. The well should be sealed against the entry of, and possible contamination from, shallower water. The lip and platform should be reasonably high, and the cover should be effective. These are the most important structural aspects preventing contamination.

In areas where a well exists, sources of contamination and their distance from the well should be investigated carefully, including the number and size of latrines, manure pits, dirty-water ponds, sewage, and garbage pits. The quantity and nature of pollutants and the degree of possible contamination should be estimated. Items for investigation include what equipment is used to draw water (e.g., buckets), whether the well is privately or publicly used, and whether there are any rules or regulations for maintenance, management, and cleaning. In other words, water-quality investigation consists primarily in understanding the likelihood of contamination. Physical criteria are usually only judged by the human senses. However, a water sample can also be sent for analysis.

The method of disinfection should depend on the local conditions and available resources. To prevent epidemics, it is essential to investigate the effectiveness of disinfection in killing pathogens and viruses. The occurrence and spread of infectious diseases should be investigated from the information supplied by local people.

For newly built wells, the hydrogeologic conditions, the depth of the water-bearing layer, the soil conditions, and the well structure should also be investigated. For other sources (rivers, lakes, reservoirs, ponds), methods and items of investigation are quite similar; that is, they include assessment of the general situation, structure and equipment of water intake, surrounding hygienic conditions, usage and management of the source, the possibility of contamination and pollution discharged upstream, and quality and quantity of the source water. Knowing these, one can improve the water source and its quality.

Chapter 2

Source Selection and Protection

Water in nature is continuously recycling. The hydrologic cycle includes precipitation (snow, hail, sleet, and rain), which reaches the ground surface and eventually becomes streams, from which part will be evaporated. The streams go into rivers, lakes, seas, reservoirs, etc., which become surface water supplies. Water that percolates into the ground, known as groundwater, also becomes a source of water supply. Groundwater can be classified as shallow and deep. A spring is the discharge of groundwater from an aquifer. An understanding of the characteristics of water quality from the various sources enables one to make a better decision in source selection.

Surface Water Sources

The common characteristics of surface water are that it contains few minerals, is not very hard, is usually large in volume, and is convenient for many people. It is, however, easily contaminated, and its turbidity and total bacterial counts are high. It is also difficult to protect.

These characteristics all apply to rivers, although the diluting and self-purification capacities of rivers are also very high. River-water quality varies with the season and precipitation; it also varies with the rate of flow. During the dry season, the turbidity is usually low, but the degree of hardness and salt content, high. During flooding, turbidity and total bacterial counts are high, whereas the degree of hardness and the salt content decrease. Wastewater from domestic or industrial discharges may pollute the river and exceed its capacity for dilution and self-purification. In such cases, not only does the quality deteriorate, but the danger of disease increases.

Lakes are slow-moving, so the water they contain is retained for long times. Suspended solids settle to the bottom, and the result is low turbidities and bacterial counts. Photosynthetic organisms grow in lakes during the summer when solar radiation is greatest, thereby seriously affecting the water quality. During the autumn, these algae die, producing a distinctive odour and colour. Thus, lake-water quality changes with seasonal variation and precipitation but to a much smaller degree than does river water. Reservoirs behave similarly to lakes, but generally the water has a higher mineral content.

Pond water termed "dead water," cannot purify itself as easily as it is contaminated, and contamination can be serious, especially in inhabited areas. Ponds commonly have an odour, as the water contains large quantities of organic matter and bacteria. In summer, aquatic weeds and plankton worsen the water quality.

Groundwater Sources

Shallow groundwater is replenished from surface water sources that are relatively nearby. Because such water only travels a short distance, natural filtration is limited, and the quality of the water may be poor. Shallow groundwater can easily become contaminated if there is any source of pollution on the surface or in the ground. Both quality and quantity are clearly affected by the surrounding environment.

Deep groundwater is generally replenished by a source further from the collection site. Due to the long distance it travels, through natural filtration in water-bearing soil strata, deep groundwater has low turbidity and can usually meet health standards for drinking and domestic use. However, deep groundwater may contain various kinds of salts and can be very hard. Some sources of deep groundwater have a high concentration of iron, fluoride, and magnesium. Most of those sources contain few bacteria, certainly fewer than surface water.

Source Selection

China is a socialist country; the water resources are the property of the people. Sources are selected according to political as well as economic and technological benefits. The following characteristics are pertinent in source selection:

- Abundance. The source must fulfill the requirements of consumption — the selection taking the weather and the local patterns of water use into account. For example, people in southern China use more water than those in the north, and there are seasonal differences in water consumption.

The quantity of water must satisfy not only current consumption but also future demands. Water should be available during both dry and rainy seasons. Therefore, when the source is being chosen, hydrologic and hydrogeologic studies should be strictly and accurately carried out. If a water source is selected during the rainy season, when water is abundant, it may be unable to meet the demands during the dry season. The variation is large, especially in mountainous and semi-mountainous areas where water may be not available at all during the dry season.

- Quality. The water should be odourless, colourless, and tasteless; it should not contain harmful amounts of chemicals or be contaminated. For these reasons a full investigation should be undertaken before a water source is chosen. The water should have good physical characteristics and should be hygienically safe. Where water treatment consists of just adding chlorine, the coliform count should not exceed an average 1000/l of raw water. The levels of toxic substances in water must be lower than those indicated in Appendix 4, as present waterworks technology is not able to reduce the concentration of those chemicals. High concentrations of fluoride or negligible levels of iodine — the latter indicated by a high prevalence of goitre in a locality — are not acceptable in the selected source. For the small, simple waterworks the best source is one in which the quality of the untreated water is as close as possible to the required standard.

- Hygienic environment. The source should be easy to protect from contamination. Wells should not be drilled near rubbish piles, dung pits, graveyards, or in undesirable soils, as they could affect the water quality.

Groundwater should be used where available, and surface water only considered as an alternative where no groundwater is available or drilling is extremely difficult. No physical connection is permitted between water used for agriculture or aquaculture and that for drinking purposes.

Water collection, purification, and transmission facilities are interdependent. For example, when the raw water is of poor quality, it is costly and difficult to purify, and maintenance and management are more complex. Similarly, if collection is difficult, construction and pumping costs increase. The source thus affects the investment required for the whole system. If there are several potential sources available, each should be assessed from technical and economic viewpoints before one of the alternatives is selected.

Once the source has been decided upon and the waterworks built, the system must be carefully protected from contamination, a side-effect of human activities.

Dung contamination is caused by seepage from latrines and by rainwater and irrigation washing over the ground's surface, especially in areas where dung is used as fertilizer on the field. It is a major contributor to the spread of infectious diseases. Therefore, wells should be drilled at elevated, slightly sloped sites. An impervious apron, a cover, and a rim should be constructed for the well. There must be no rubbish piles, dung pits, or cattle pens within 30 m of the well. Laundering and the washing of night-soil buckets should be prohibited within 3 – 5 m. The structure for the well should be made of watertight material, such as brick, stone, or concrete.

If a surface-water source (lake, reservoir, or pond) is used, an area around it should be protected as a water-catchment area, with no latrine, dung pit, or other polluting agent allowed near the shore. Laundering, washing night-soil buckets, and discharging wastewater into the water should be prohibited, as should swimming and fishing. If river water is used, the site for drawing water should be upstream of any wastewater discharge or docking facilities. Similarly, all wastewater or solid-waste discharge should be prohibited upstream of the chosen site.

The dangers from contamination by industrial wastes are increasingly being recognized, and prevention of industrial pollution is a priority. The most effective measure is the treatment and reuse of wastes within the industry, with the purpose of minimizing the harmful chemicals discharged. Industrial wastewater should be discharged into a drainage system not into a source of water supply.

To protect domestic and drinking-water supplies from contamination, the standards laid down in Appendix 4 are a good reference.

Chapter 3

Source Improvement

Source protection and improvement are permanent methods of ensuring the water quality against bacterial, harmful chemical, and other pollution. In contrast, disinfection is a continuing task that does not deal with the cause of pollution. In China, where emphasis is put on prevention, techniques for improving water sources are preferable to disinfection, and they should be part of the barefoot doctors' curricula. They begin with the collection of information on hydrologic conditions and source characteristics. The following are simple methods that improve surface water, spring water, and groundwater supply systems.

Improving Surface Water

Surface water is exposed to the atmosphere and is therefore easily contaminated; it is not as good as water from other sources. In fact, in many areas, wells have been drilled (especially deep wells) to replace surface-water sources — a practice that is recommended but not always possible. The other alternative is to improve the surface-water source.

One method is to build a natural infiltration well (Fig. 1) near a river or pond that contains potable water. The only prerequisite is that the subterranean strata be able to transfer water or that a water-bearing stratum exists so that the river or pond water filters into the well and is purified by the sand stratum.

Another method is to construct a sand-filter well (Fig. 2–4), for which there are many designs. The basic principle is utilizing sand to filter water. The water is purified by the operation of two mechanisms: the small openings between the grains of sand do not permit undesirable substances to pass through with the water and a biological layer on the sand, which is created by microorganisms, absorbs many of the undesirable substances.

When newly constructed, the well may not filter satisfactorily, especially if turbidity is high; however, when the biological layer has been created, the water quality improves.

The size of particles affects the effectiveness and rate of filtration. If the grains are too small, the filtration may be good but slow and will require a large surface area. Large grains increase the filtration rate but with poor results. The particle size used in the filter should reflect the turbidity of the raw water. Riverbed sand is usually satisfactory, once the larger particles are picked out and the tiny ones removed with a wicker basket and fine sieve.

The thickness of the filter also has an important affect on filtration. It is usually between 0.5 and 1.0 m thick but should be thicker if the sand in the bed is coarse, thinner if the sand is fine. The filtering bed area is calculated from the consumption and filtration rates. According to the design promoted by the Public Health and Epidemic Prevention Station in Hebei province, if the particle radius is 0.3–0.5 mm, the bed should be approximately 0.8–1.0 m deep, the filtration rate being 0.1–0.3 m/h (i.e., 0.1–0.3 m^3 of water through 1 m^2 of filter area per hour) (Table 2).

When the height of the filtering well is calculated, besides the depth of the bed, a supporting layer and a distance between the sand and the top

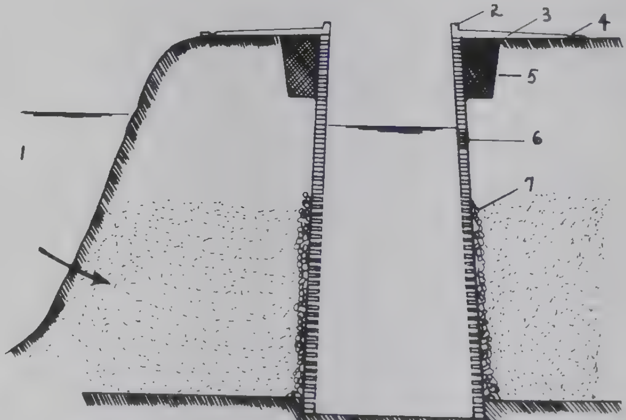


Fig. 1. Natural infiltration well (1, river water; 2, lip; 3, impervious apron; 4, ditch; 5, clay; 6, seal; and 7, pebbles or broken brick).

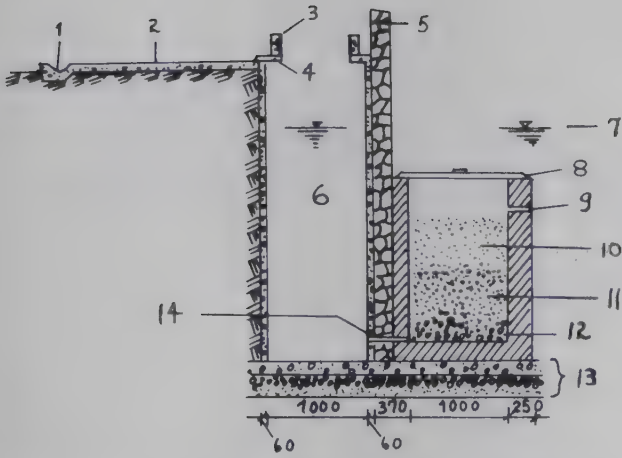


Fig. 2. Sand-filtering well (1, ditch; 2, impervious apron; 3, lip; 4, corner platform; 5, protection wall; 6, treated water tank; 7, flood-season level; 8, cover; 9, water intake; 10, fine sand; 11, coarse sand; 12, pebbles; 13, foundation; and 14, inlet).

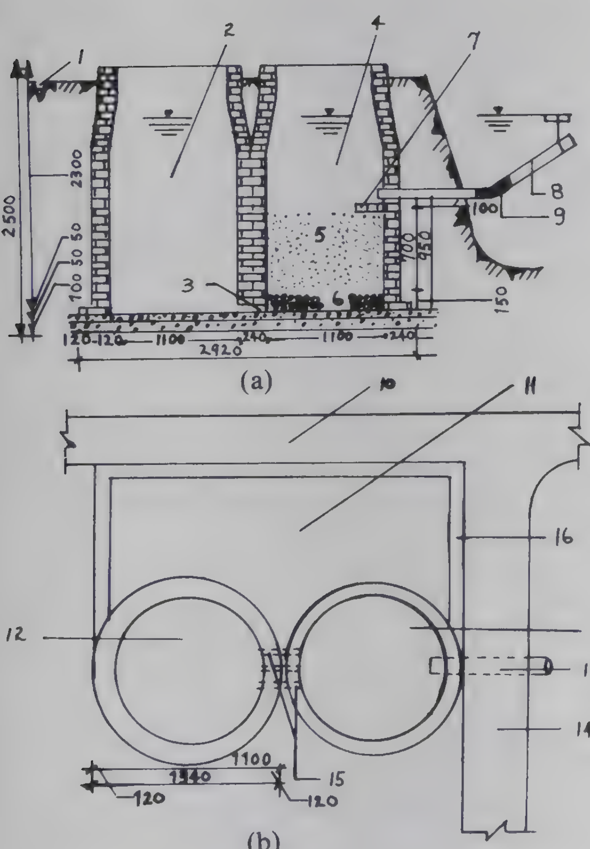


Fig. 3. Sand-filtering well: (a) the cross section (1, ditch; 2, pure-water tank; 3, water inlet; 4, sand-filtering well; 5, coarse sand; 6, pebbles; 7, stepping brick; 8, intake pipe, bamboo; and 9, rubber joint); (b) the plan (10, earth; 11, impervious apron; 12, pure-water tank; 13, sand-filtering well; 14, earth; 15, water inlet; and 16, ditch).

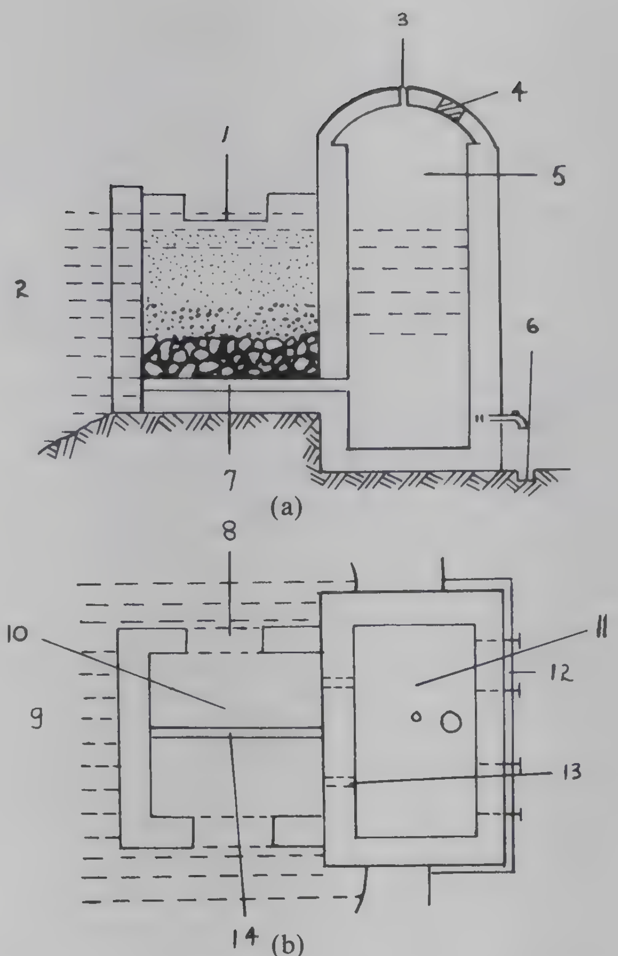


Fig. 4. Sand-filtering well: (a) the cross section (1, intake, 55 mm higher than the sand surface; 2, source; 3, vent; 4, entrance; 5, pure-water tank; 6, ditch; and 7, drain); (b) the plan (8, intake; 9, source; 10, sand-filtering well; 11, pure-water tank; 12, ditch; 13, drain; and 14, drain).

should be taken into account. The supporting layer could be 0.15–0.3 m thick. The water above the sand surface will exert pressure on the bed and help to increase the filtration rate. After a period of operation, the openings in the sand filter become blocked and the filtration rate decreases; 5 cm of sand is taken off the surface layer, washed, and replaced. If the filtration rate does not then recover, all the sand must be removed and thoroughly washed; this should be necessary only after the filter bed has been in use for a relatively long time.

Surface Water Collection

For surface water schemes, intake structures can be either fixed or movable. The fixed intake conduit is usually placed beside a reservoir or in a

Table 2. Data for filter and pure-water well design.[a]

Households (no.)	Filter tank			Treated water tank		
	Tank depth (mm)	Diameter (mm)	Filter area (m^2)	Well depth (mm)	Diameter (mm)	Max. water content (m^3)
30	2300	1000	0.785	2300	1000	1.5
40	2300	1100	0.95	2300	1100	1.8
50	2300	1200	1.13	2300	1200	2.15

[a]The calculation is based on summer water consumption (20 litres/person-day) with five persons per household.

riverbed. If the slope of the reservoir or riverbank is steep, and the geologic structure good, the intake conduit can be built right into the bank, or if the mainstream is far from the bank and the water quality near the shore unsatisfactory, the conduit is usually built right into the riverbed, provided the bed is flat and stable.

If the intake conduit is movable, it is placed on a boat or cable car so that water can be collected even where the water level varies between 10 and 35 m. The water level should not fall or rise more than 2 m/h, and the shore should be reasonably sloped (10°–30°). There should be no solid objects floating on the water and no risk of collision by boats. In other words, the sites chosen for movable conduits should be safe and easy to manage (Fig. 5).

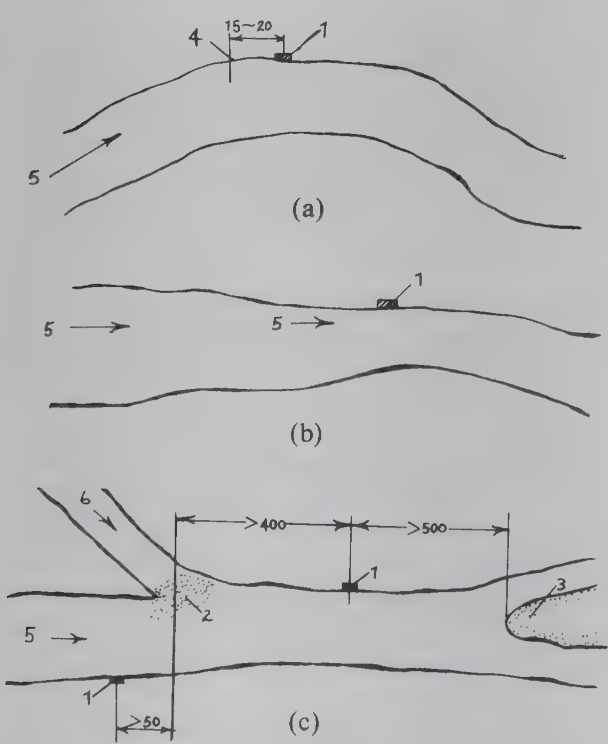


Fig. 5. Collection sites for surface water (1, intake siting; 2, accumulation [sludge, sand, etc.]; 3, island; 4, heading point; 5, mainstream) in (a) a winding river, (b) a straight river, and (c) a branched river with island.

Where the river is winding, the direction of the mainstream should be carefully investigated and the catchment should be sited downstream where the water is deep (Fig. 5a).

If the river is fairly straight, the intake should be sited as close as possible to the mainstream; a narrow section of the river may be optimal (Fig. 5b). However, some hydraulic effects may occur after the intake structure is built, and the shape of the river may change.

If there is a sandy island in the middle of the river, the collection point should be sited at least 500 m away (Fig. 5c, right), and if the island is at the mouth of one of the branches, the collection point might be better sited upstream in the other branch (Fig. 5c, left).

Uncontaminated spring water is suitable for drinking, but it must be protected from contamination. The greatest emphasis should be placed on improving the surrounding environment. Any pollution source within 30 m — latrines, cattle pens — should be removed. A sealed enclosure should be constructed of brick, stone, or concrete, and a tap should be installed (Fig. 6).

If the spring water is abundant, it can be transmitted to the community by a system combining a pure-water tank and a pipeline (Fig. 7). It will be sanitary, convenient for the users, and easy to maintain.

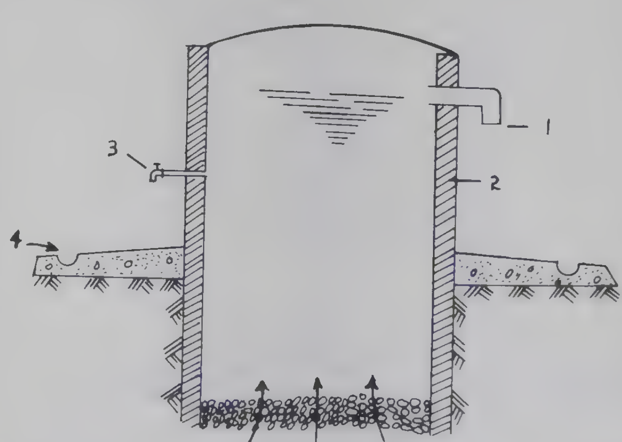


Fig. 6. Sealed spring (1, overflow; 2, tight wall; 3, tap; and 4, ditch).

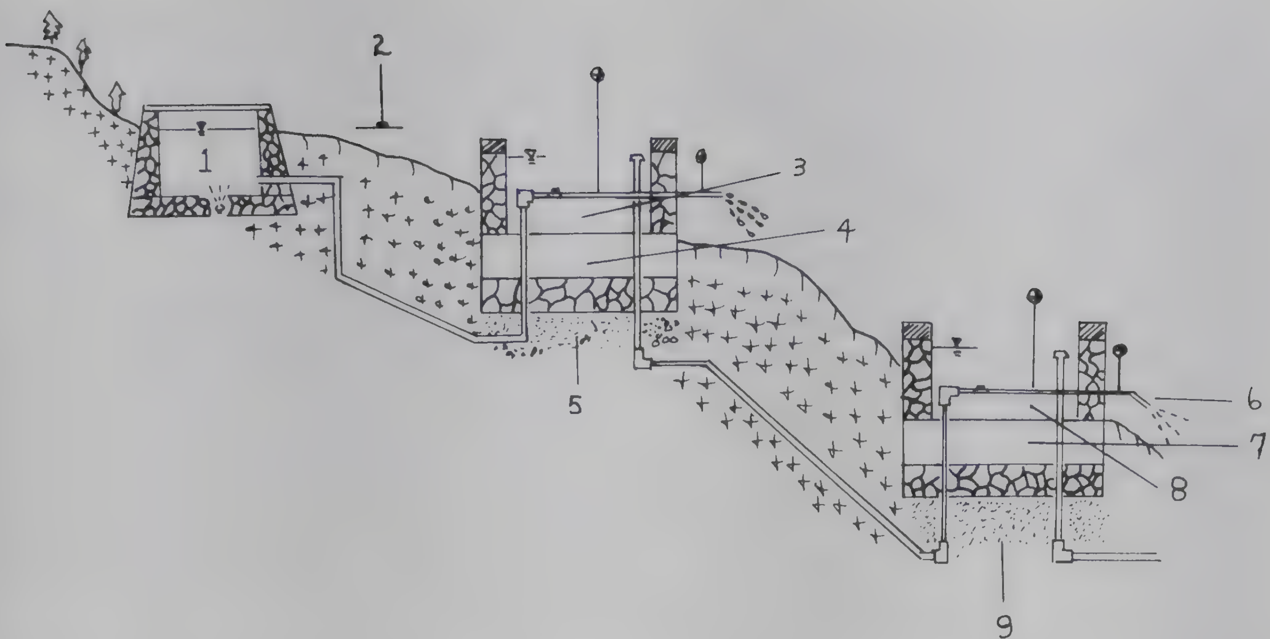


Fig. 7. Transmission of spring water (1, source enclosure; 2, 7.5 m; 3, pure-water tank; 4, concrete; 5, sand; 6, tap; 7, concrete; 8, pure-water tank; and 9, sand layer).

In the mountainous areas of Fujian and Guangdong provinces, spring water is abundant and does not need treatment. Also, it is easily transported by gravity to the community — a cheap and convenient water supply. The pipeline may be bamboo, concrete, porcelain, clay, or plastic.

If bamboo is used, it should have its "skin" taken off, the nodes pierced with a sharp tool and scraped, and then it should be thoroughly cleaned several times in water so that the water piped through it doesn't acquire an odour. Burying the bamboo pipeline will make it last longer; a lifespan of 2–3 years is normal. Sections of either concrete or porcelain pipelines should be joined with a mortar of cement : sand (ratio 1 : 2). If the joints do not seal well, sodium silicate or potassium silicate should be added to the mortar.

Spring water for drinking purposes should be

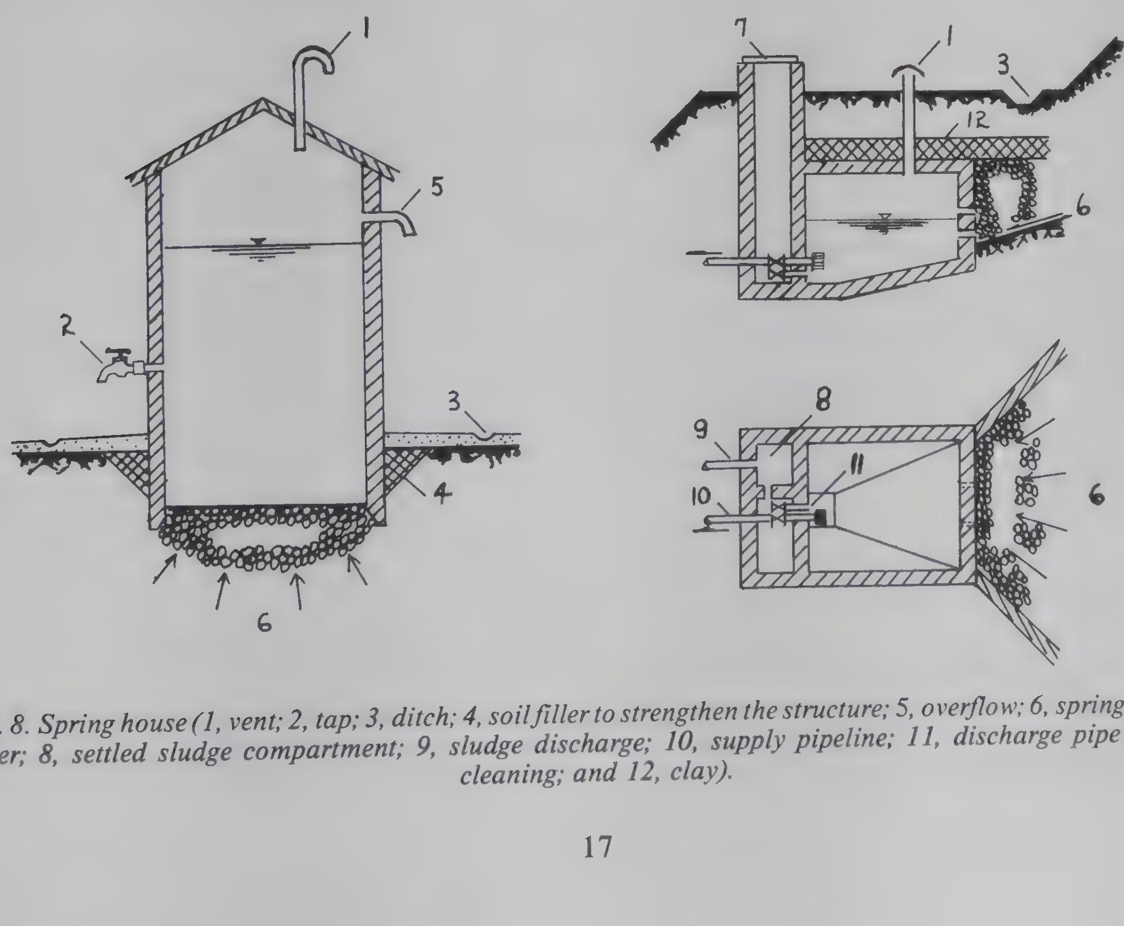


Fig. 8. Spring house (1, vent; 2, tap; 3, ditch; 4, soil filler to strengthen the structure; 5, overflow; 6, spring water; 7, cover; 8, settled sludge compartment; 9, sludge discharge; 10, supply pipeline; 11, discharge pipe for tank cleaning; and 12, clay).

far from pollution sources but near enough to users to be convenient. The discharge point of a spring can only be found by site investigation and visits. Long-time residents are the best experts on how and where to look for a spring.

Most communities in mountainous areas are small and scattered, so the piping structure should be simple, low cost, and convenient. A "spring house" (Fig. 8) is sometimes desired, and it can be built with local materials, near the point of use. Bricks, blocks of stone, and concrete are the common building materials.

The steps to collect water and protect it from pollution are to:

- Install a watertight cover with a vent that opens downward and with a screen that prevents insects from entering;
- Design all entrances so that pollution is minimized; for example, an entrance should not be too close to the ground;
- Ensure walls are impervious; clay should be used as a seal on the outside of the wall to a thickness of 0.3–0.5 m;
- Construct a slanted, impervious apron around the house to prevent polluted water from seeping in;
- Build a "spring house," which is a sealed enclosure, on impervious bedrock; the site is important for maximum water collection; and
- If water is to be taken directly from the spring house, provide a tap or a public bucket.

The Hondi production team in Fujian province uses a spring house to collect its water. The water is then transmitted through 450 m of pipe (a shortened version in Fig. 9), the last 50 m of which is porcelain with an 80-mm diameter, into a village storage tank, built of hewn-stone blocks, with a capacity of 12 m^3. Four taps have been installed in two sides of the tank. A lever valve permits a large volume of water to be drawn in just a few seconds. Bathroom and laundry facilities are located next to the tank.

The Qile production team in Guangdong province also uses a spring house but uses bamboo to transmit the water to the village (Fig. 10). The junctions between sections of bamboo were sealed with tar and reinforced with cement mortar on the outside. The pipeline was buried but marked with stakes for ease in maintenance.

Groundwater Collection

Structures for groundwater collection depend on the depth and thickness of the aquifer, on hydrologic conditions, and on the quantity of water required. Collection can be divided into two categories: drilled, dug wells, and infiltration galleries (Table 3). In rural areas with scattered populations, other well types — built of bamboo or with a spring house — are used for groundwater collection.

Hydrogeologic conditions generally determine where a groundwater collection facility should be installed. It should be sited where water is abundant and as near as possible to the major users. Other factors, e.g., the capital available for engineering and construction; people and means available for operation, management, and maintenance; should also be considered. Furthermore, the possibility of contamination should be taken into account, and the replenishing source and its path of flow should be estimated. Sources for domestic and drinking-water supply should be located upriver from towns, cities, inhabited areas, and industrial areas.

The Bamboo-Built Well

A bamboo well uses the simplest equipment for collecting subsurface percolating water and shallow groundwater. In the Shanghai suburban area, where the groundwater table is high (usually less than 1 m below ground surface), the bamboo well is used for single-family water supply (Fig. 11 and 12). It is inexpensive, easy to make, and the material (bamboo) is available everywhere. A bamboo-built well is usually installed indoors (kitchen) to minimize the possibility of contamination and to maximize the life of the well.

Kitchen Well

The kitchen well is another simple structure for drawing subsurface percolating water or shallow groundwater (Fig. 13). It is named for its location in or near the kitchen. The advantages of a kitchen well are that it is inexpensive and easy to build, usually only 3 m deep and requiring no more than 2–3 work days. The materials needed for construction are 300–400 bricks and a short section of concrete pipe with an internal diameter of 400 mm; the total cost is only 20–50 yuan. Because the kitchen well is installed in individual houses, it is convenient to use and maintain and is little susceptible — if at all — to contamination during seasons when fertilizer is used in fields.

The minimum space between the well and cattle pens or latrines is 5 m. If the sanitary conditions in the kitchen are poor, strict rearrangement of connections and disposal is required before the well is built.

Before construction of the well, the building materials should be washed. After construction, the first few draws of water should be discarded;

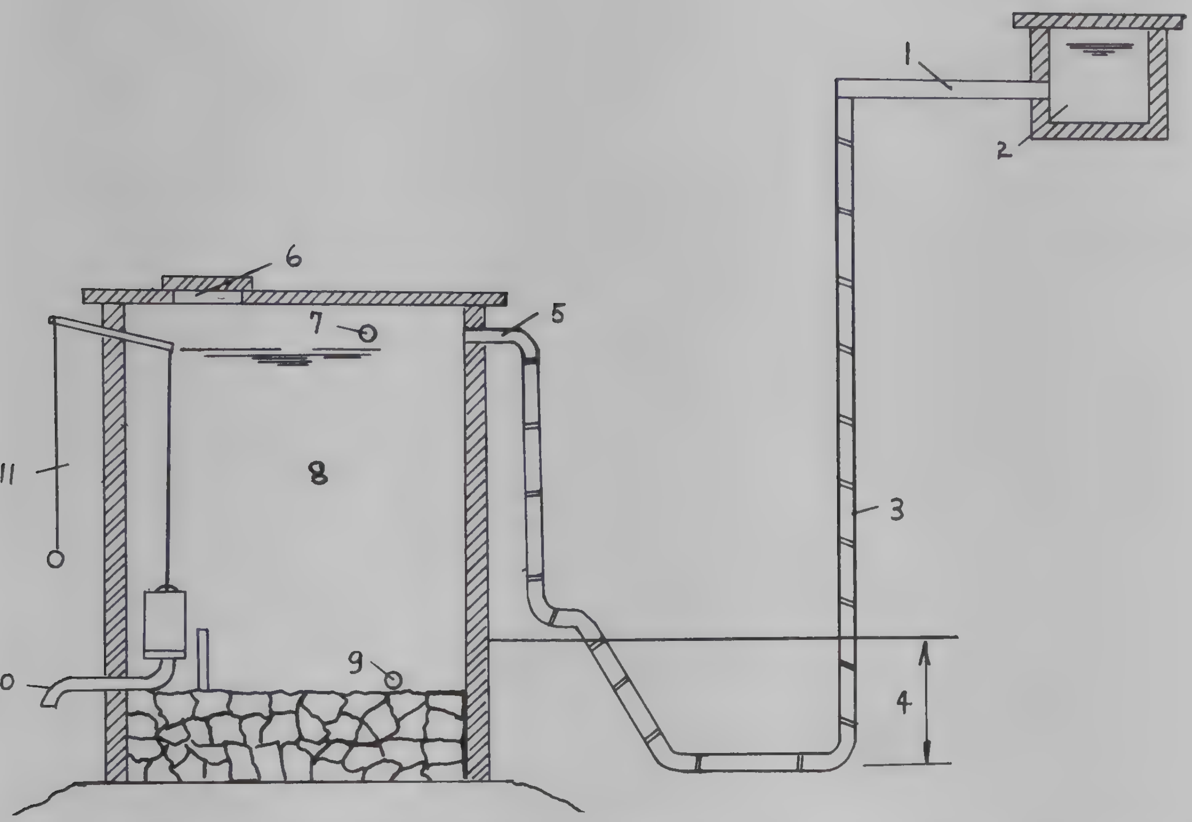


Fig. 9. Diagram of Hondi production team's spring water system (1, triangular channel; 2, spring water; 3, porcelain pipe; 4, buried portion of pipe 1 m underground; 5, inlet; 6, access for repairs, adjustments, etc.; 7, overflow; 8, storage tank; 9, pipeline to supply; 10, outlet; and 11, pull that releases valve for water discharge).

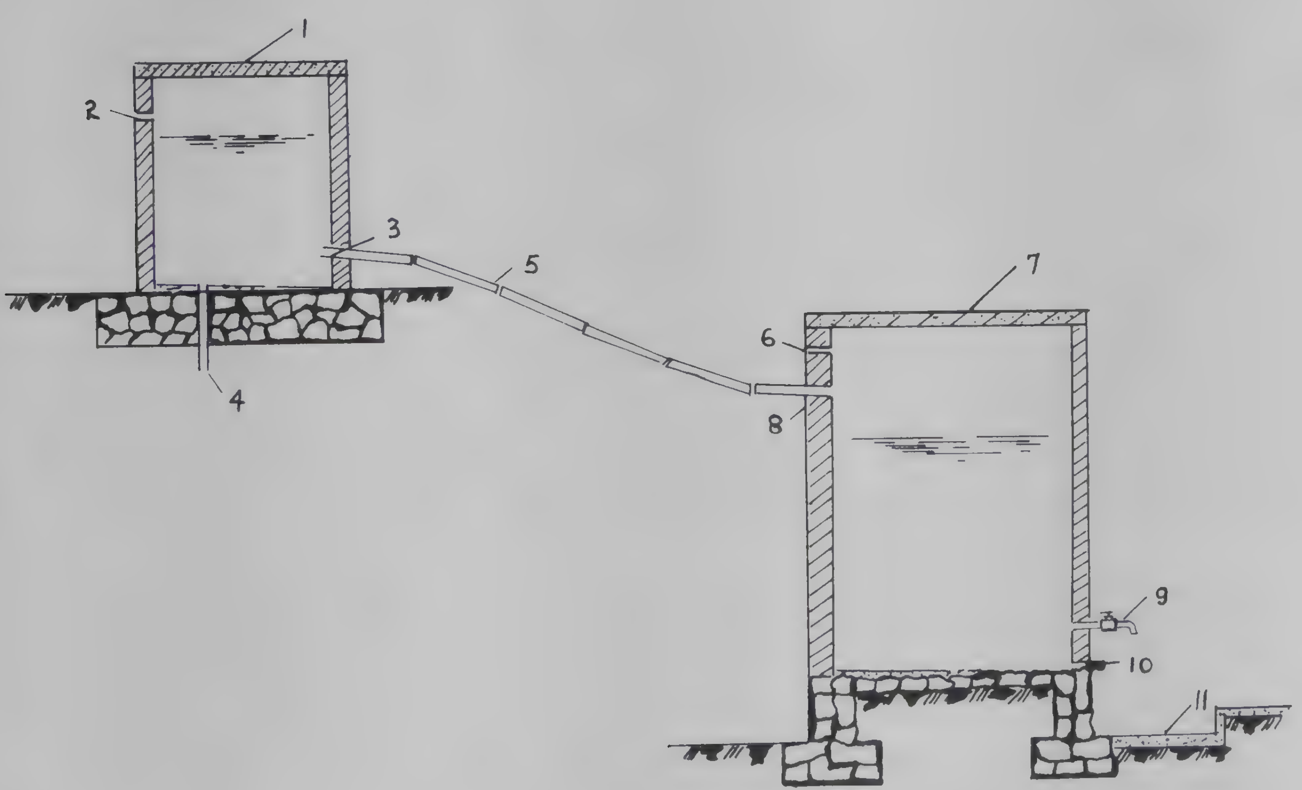


Fig. 10. Diagram of the Qile production team's spring water transmission (1, source-protecting tank; 2, overflow; 3, outlet; 4, spring-water inlet; 5, bamboo pipeline; 6, overflow; 7, storage tank; 8, inlet; 9, tap; 10, sludge discharge; and 11, ditch).

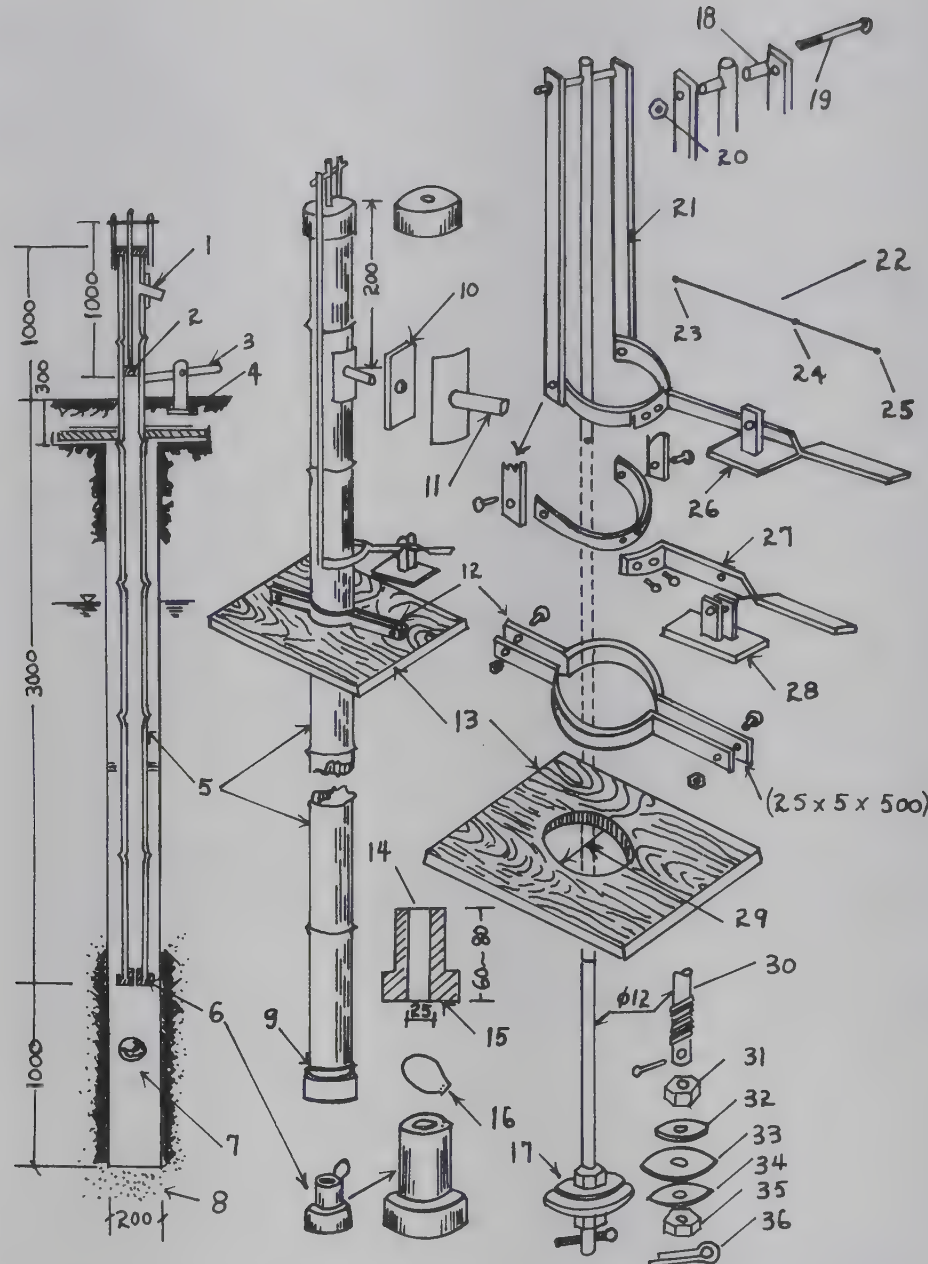


Fig. 11. Bamboo-built well (1, steel tap; 2, piston; 3, pedal; 4, supporting plate; 5, bamboo; 6, unidirectional valve; 7, water storage; 8, sand layer; 9, galvanized wire; 10, rubber gasket; 11, 30-mm-diameter steel tap; 12, fitted frame; 13, wooden plate; 14, hole; 15, unidirectional valve; 16, rubber piston cover; 17, piston; 18, 10-mm-diameter jacket; 19, long bolt; 20, nut and retainer; 21, link: 20 × 3 mm steel plate, length: 900–1000 mm; 22, lever; 23, loading; 24, supporting joint; 25, force; 26, supporting plate; 27, flat steel bracket for pedal, 30 × 5 × 200 mm; 28, steel plate; 29, diameter decided by the external diameter of bamboo pipe; 30, lever; 31, nut; 32, retainer; 33, rubber washer; 34, retainer; 35, nut; and 36, pin 3 × 20 mm).

then the water can be used. Drilling more deeply into the ground produces more and better water. The diameter of the body of the well, especially at the bottom, can be reduced as a cost-cutting measure.

The Sealed, Dug Well

The sealed, dug well prevents pollution or contamination from the use of buckets. Of the many designs for this type of well, the most frequently used are the draw well with hand pump (Fig. 14), draw well with waterwheel (Fig. 15), and draw well with windlass (Fig. 16). For the first two, the water surface should not be more than 5–6 m underground, or drawing water will be difficult. If the hand pump is difficult to use, it can also be modified so that the piston of the pump is under water. This modification causes the piston to push the water up rather than using a

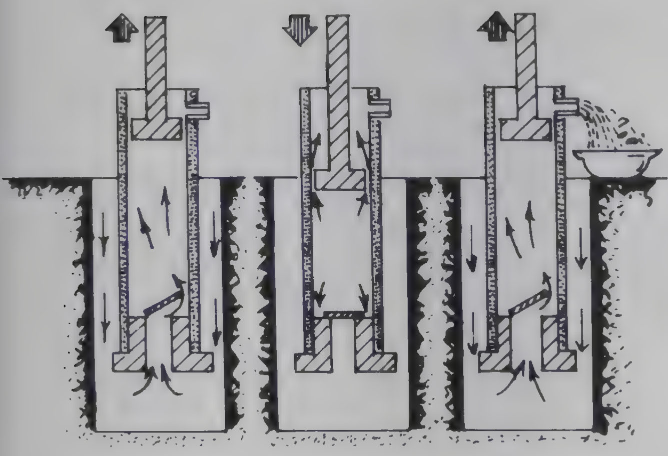


Fig. 12. The bamboo-built well in operation.

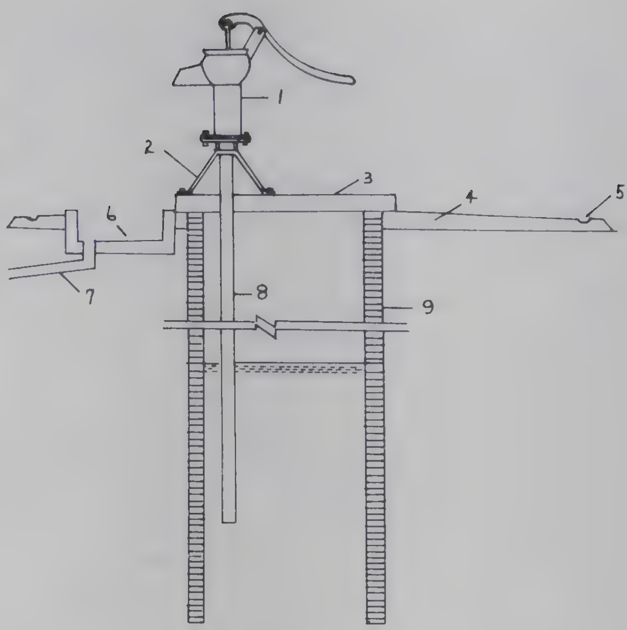


Fig. 14. Draw well with hand pump (1, hand pump; 2, supporting frame; 3, cover; 4, impervious apron; 5, ditch; 6, position for bucket; 7, ditch; 8, intake pipe; and 9, seal).

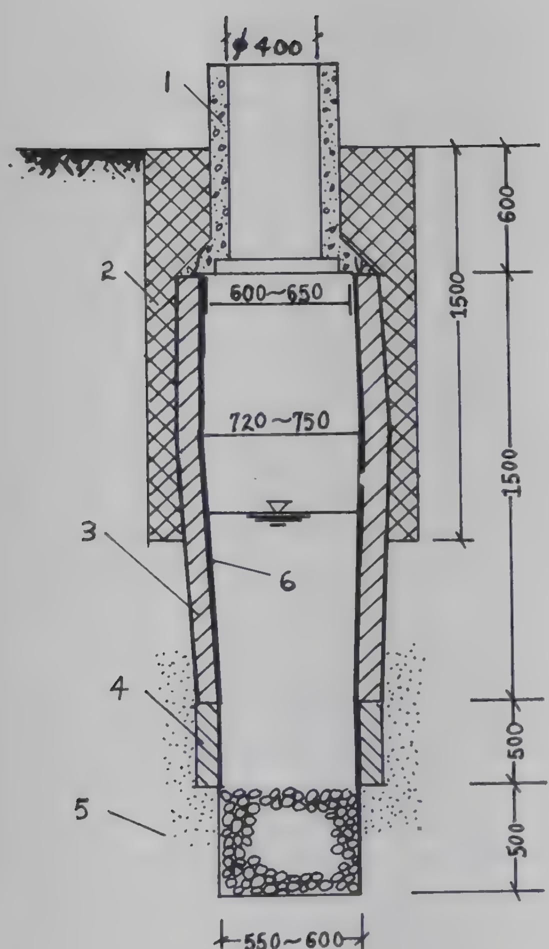


Fig. 13. Cross section of the kitchen well (1, cement pipe; 2, clay stabilization; 3, brick wall sealed by cement; 4, brick without cement; 5, sand; and 6, polished cement mortar).

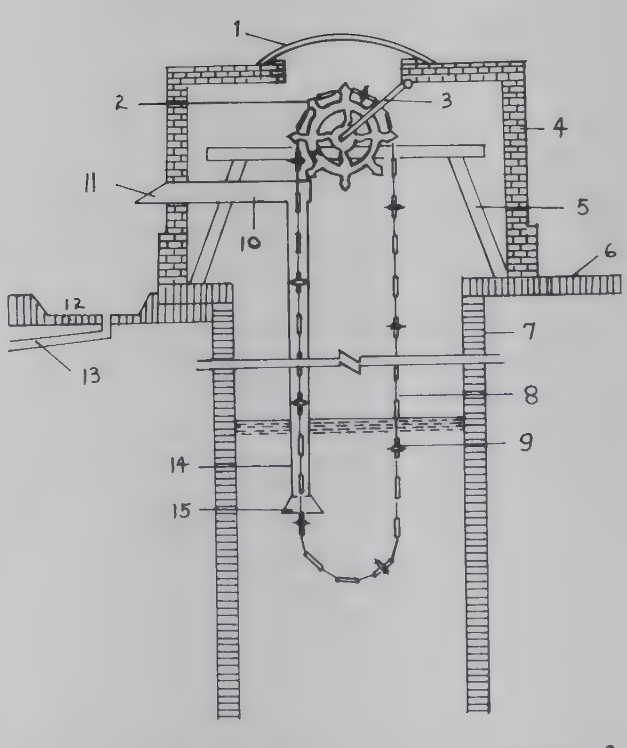


Fig. 15. Draw well with waterwheel (1, entrance; 2, wheel; 3, handle [for turning]; 4, tight seal; 5, frame; 6, impervious apron; 7, well seal; 8, iron chain; 9, leather washer; 10, trough; 11, outlet; 12, position for bucket; 13, ditch; 14, intake pipe; and 15, bell).

Table 3. Groundwater collection technologies.

Category	Scale	Well depth	Hydrogeologic conditions: Aquifer depth	Aquifer thickness	Characteristic	Production
Drilled well	Diameter of well 50–1000 mm but usually 150–160 mm.	20–1000 m, but usually less than 300 m	Dependent on pumping capacity, no maximum	Usually thicker than 5 m, or a multiple water-bearing stratum	Suitable for sand, gravel, or pebble stratum	Generally 500–6000 m^3/day for a single well; maximum 20 000–30 000 m^3/day
Dug well	Well diameter, 2–12 m but usually 4–8 m	Less than 30 m, usually 6–20 m	Very shallow, usually less than 12 m	Generally 5–20 m	In-flow and percolation are good; percolation index should be higher than 20 m/day; suitable for sand or gravel stratum	Generally 500–10 000 m^3/day; maximum 20 000–30 000 m^3/day
Infiltration gallery	Pipe diameter 0.45–1.5 m but usually 0.6–1.0 m	Greater than 10 m but conventionally 4–7 m	Very shallow, usually less than 2 m	Very thin, usually 4–6 m	In-flow and percolation are good; suitable for the middle sized or coarse sand stratum, or gravel, pebble stratum	Generally 15–30 m^3/day-m; maximum 50–100 m^3/day-m

vacuum. If the well is deep, the windlass should be used.

A windlass carries the water up in a round-bottomed bucket and lets it out through a trough. Some designs use a large stone as an anchor at the well bottom and two lengths of wire extending from the stone to the top as a track. The bucket travels between wires through two holes on both sides of the bucket and can thus move steadily up or down. A stophook is placed at the top, which causes the bucket, once it reaches the top, to tilt and pour the water down the trough.

A tight seal for a well with a windlass or waterwheel can be made of wood, brick, or concrete. Only the end of the trough and handle are outside the well. Improvements for existing wells include cleaning the bottom by withdrawing the slurry and introducing a layer of sand, moving cattle pens, and filling in latrines and rubbish or manure pits within 30 m. Also, the walls of the well should be sealed and an impervious apron built, 20–30 cm aboveground. The apron should be sloped, and a ditch should be made at the outside edge so that no polluted water flows into the well. All these measures are essential for well protection.

Small-Mouthed Well

The traditional well has a big opening and shaft, which are difficult and costly to repair or rebuild; it is easily contaminated and hard to protect; therefore, a small-mouthed well is recommended where the water table is high enough (Fig. 17).

The small-mouthed well has a shaft 20–25 cm in diameter, the opening is even smaller, with a diameter of 15–20 cm. The well shaft can be made of bamboo, earthenware pipe, concrete pipe — whatever is locally available. A layer of pebbles or sand should be laid on the bottom of the well, and it should be cleaned periodically. A sloping impervious apron should also be built

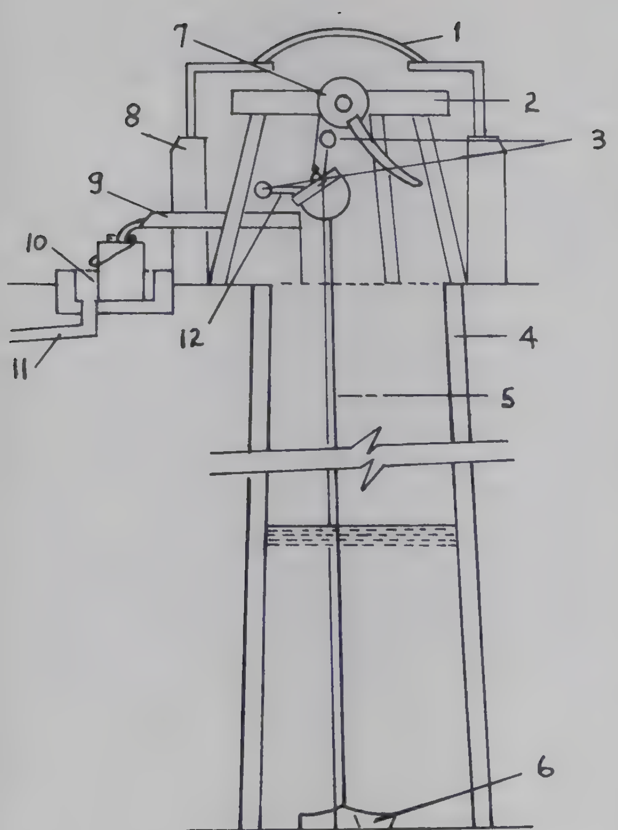


Fig. 16. Draw well with windlass (1, entrance; 2, frame; 3, fixed shaft; 4, seal; 5, track; 6, fixed stand; 7, windlass; 8, tight seal; 9, trough; 10, position for bucket; 11, ditch; and 12, stop hook).

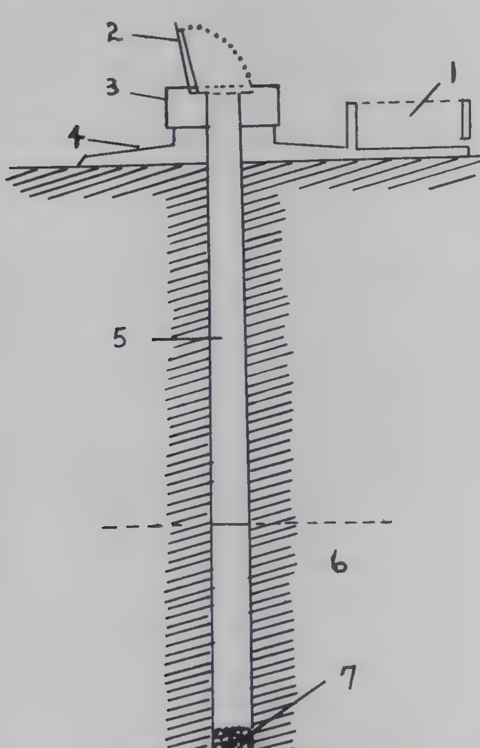


Fig. 17. Cross section of a small-mouthed well (1, tank; 2, cover; 3, lip; 4, impervious apron; 5, well body; 6, water-bearing layer; and 7, pebbles or sand).

around it. A curved, iron spade can be used to drill a small-mouthed well. The spade should be approximately 30 cm long (Fig. 18) with teeth on both sides. The shaft handle is a horizontal rod, fixed to the apparatus with cord; its length will depend on the height of the water table but is usually about 7 m. The other end of the cord can be tied to the spade to prevent it from dropping into the well.

A person holds the spade in position, pushing downward on the handle, while two other people push the horizontal rod to make the shaft rotate. At the same time, water is added to the hole to make some of the soil into slurry, which will cause the soil to stick to the spade and come out easily when the spade is withdrawn. The soil is removed in this way after the shaft is rotated several times. When the groundwater appears, the hole is drilled another 2 m deep; then the water is pumped out until it becomes clear.

The water-intake device for a small-mouthed well can be a long bucket with a piston valve at the bottom (Fig. 19). Water enters the bucket through the valve and is poured out when the string is pulled. Alternatively, a hand pump can be installed on the well.

The advantages of a small-mouthed well are that it is easy to construct and maintain. It can be installed in the yard or kitchen and is easy to use and protect.

The Driven Well

The driven well (Fig. 20 and 21) is suitable where the water table is high, the quantity of water is abundant and sand layers do not contain large rocks that could obstruct the pipe as it is being driven down. Bamboo or steel pipes can be used for the driving pipe. A steel pipe should be 2.5–5 cm in diameter; bamboo should be young stems (as old ones break easily), 7–8 m long, with a diameter of 1.5–2.0 cm (measured at the base). Both steel and bamboo pipes should be pierced 1 m from the lower end with 30–40 fine holes (0.3–0.5 cm in diameter) for water intake; these holes should be 3–4 rows, 6–10 holes per row. When bamboo is used, all the nodes should be broken except the one at the bottom. The slender part of the bamboo should point downward with wire wrapped around the end to prevent breakage. If steel pipe is used, the lower end should be made into a diagonal point.

Before the pipe is driven into the ground, a hole with a diameter of 30 cm should be drilled as deep as possible, then water poured in to soften the soil. Two or three people will be needed to insert the steel pipe perpendicular to the ground surface. A

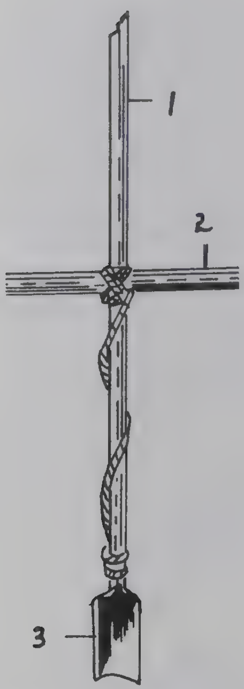


Fig. 18. Long-handled spade used in small-mouthed well (1, handle; 2, horizontal rod; 3, spade).

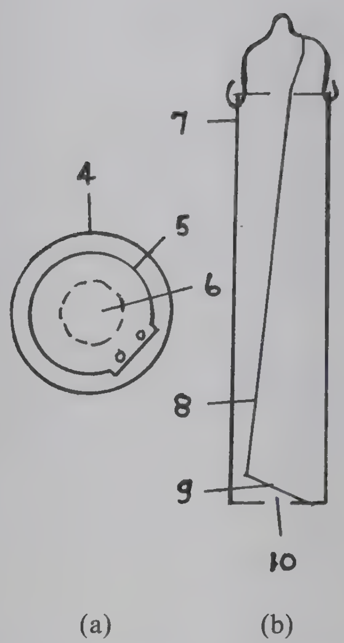


Fig. 19. (a) piston valve (seen from below) (4, bottom of bucket; 5, rubber valve; 6, water intake or outlet) and (b) bucket with piston valve (7, water-intake bucket; 8, string; 9, rubber valve; and 10, water intake or outlet).

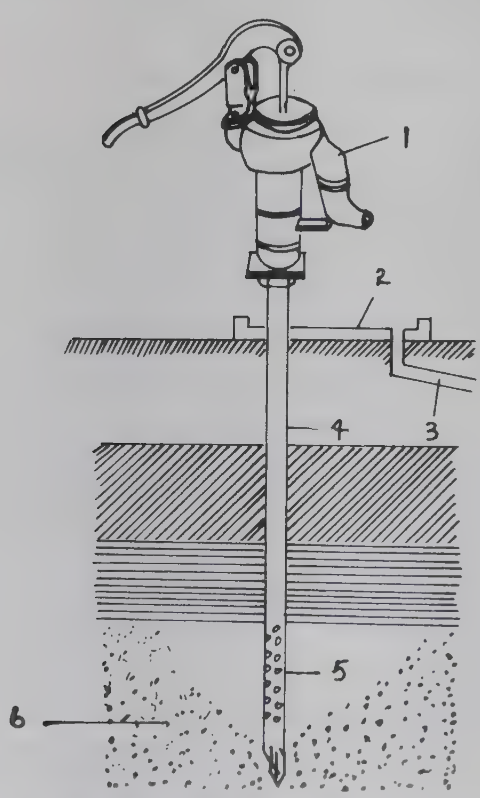


Fig. 20. Steel-pipe driven well (1, hand pump; 2, groove; 3, ditch; 4, steel pipe; 5, water-intake hole; and 6, water-bearing layer).

horizontal rod can be attached (as for the spade Fig. 18) to rotate it when the resistance becomes great.

One person should hold the pipe while it is being inserted to keep it straight and to assess the condition of the soil. Experience shows that if insertion is easy and noiseless, the earth is soft, perhaps loess with a little water in it; if insertion is difficult and the earth sticks to the pipe, it may be clay. If insertion is difficult and produces a scratching sound, the soil is probably sand. The louder the sound, the larger the sand particles, and the more the water contained in the layer. If there is a gravel stratum, the water should be plentiful, but the shaft may wobble and should be held firmly while being driven in. After the pipe is driven into the ground to an appropriate depth, 0.5 m of pipe should be above the ground surface for the hand pump installation. Water should be withdrawn until it comes out clear. If bamboo is used, a steel pipe should first be used for driving and then be replaced with the bamboo. A hand pump can be homemade with waste steel pipe and sheet. The advantage of a driven well is that it is easy to install and convenient to use.

Riverbed Percolation Well

A riverbed percolation well is a kind of wide-mouthed well, suitable for areas where the riverbed allows good percolation. In the mountains, the water level is usually low during the dry season, sometimes so low that the bed can be seen. A riverbed percolation well is suitable for this hydrologic condition, because it allows water to be collected by a drain beneath the surface of the riverbed by the well.

The site on the riverbed should be stable, with good water that is flowing rapidly. The section of river should be straight, and percolation through the riverbed should be good. The construction material is usually brick, stone rubble, or precast concrete blocks; however, local materials are recommended. The rate at which water enters the well is increased if an inlet is built into the wall of the well. It can be horizontal (Fig. 22a) or inclined (Fig. 22b).

A horizontal inlet is easy to make and is commonly used. It is usually a cylindrical hole with a diameter 100–200 mm; sometimes it is rectangular (100 × 150 to 200 × 250 mm). Inclusion of a galvanized wire screen will prevent loss of filter media.

An inclined inlet is usually circular with a diameter of 50–150 mm (maximum 200 mm).An inclined hole facilitates changing the filter media but is susceptible to blockage. The incline should

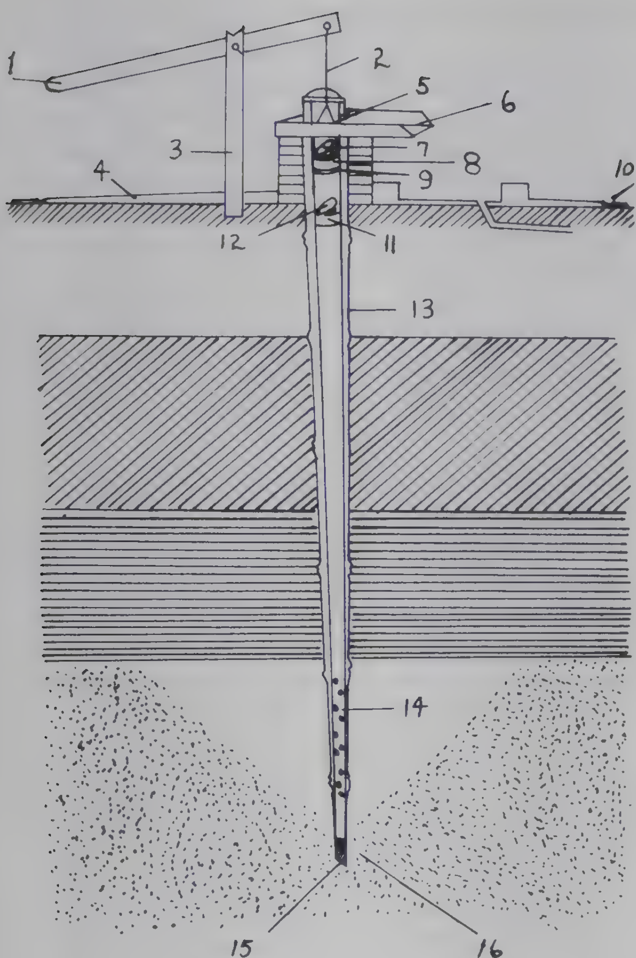


Fig. 21. Bamboo-pipe driven well (1, handle; 2, pull rod; 3, supporting post; 4, impervious apron; 5, outlet; 6, trough; 7, piston valve; 8, piston; 9, rubber gasket; 10, ditch; 11, piston supporter; 12, piston valve; 13, bamboo; 14, water-intake hole; 15, cork; and 16, wire).

not be greater than 45°, and a screen is usually put at both ends. The filter at the bottom is mainly to prevent sand from getting into the well. Usually there are three to four layers, 200–300 mm thick each, with the size of grain increasing from bottom to top. If the grains of sand in the riverbed are large, two layers of filter and a total thickness of 400–600 mm may suffice (Table 4).

On top of the well, a cover with a vent should be fitted. The vent pipe should be 1–2 m higher than the water level during the flood season. An example is a riverbed percolation well in Guangdong province, with an external diameter of 5 m and a depth of 4 m (Fig. 23). The well wall is a precast-concrete ring in two short sections, each 2 m high. The concrete ring was sunk to the required depth by dredging the sand from the bed. At the bottom, a 0.4-m layer of stones was used as a seal. Above that, 2–4 mm of medium grain sand and 4–8 mm of fine sand were placed, topped by a filter of three layers, 200 mm each, with grain diameters of 10–20, 20–40, and 40–80 mm respectively.

This well started to provide water in 1969 with an output of 1500 m^3/day and did not stop until 1975. The sand in the well was then cleaned and production resumed.

Deep Well

In the suburban areas of Shanghai, some communes use deep groundwater for their water supply. This water meets the drinking water standards and treatment is unnecessary. These communes (Caoxing, Zhangjiang, and Zhuanqiao) each use a system with one well and one storage tower. Well depth is more than 200 m, and output

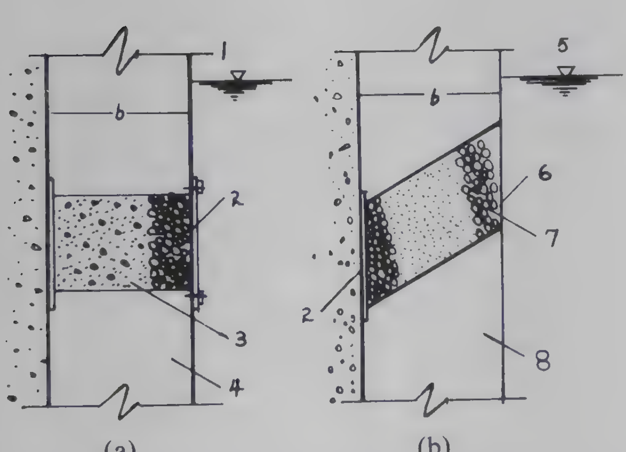


Fig. 22. Inside-view of (a) a horizontal inlet (1, inside the well; 2, galvanized wire screen; 3, filter media — sand, pebbles; and 4, wall seal) and (b) an inclined inlet (5, inside the well; 6, screen, if inlet is less than 500 mm; 7, stone; and 8, wall seal).

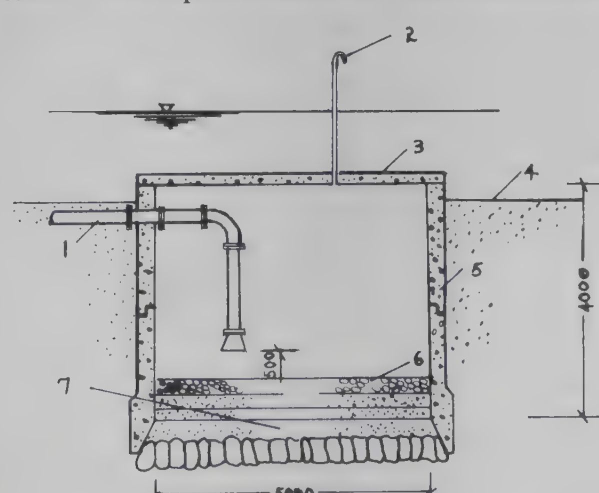


Fig. 23. Cross section of a riverbed percolation well (1, water-intake pipe; 2, vent, 50 mm in diameter; 3, concrete cover; 4, riverbed; 5, precast concrete ring; 6, pebbles; and 7, sand).

Table 4. Grain diameter and layer thickness for bottom filter.

Riverbed material	First layer		Second layer		Third layer	
	Grain diameter (mm)	Thickness (mm)	Grain diameter (mm)	Thickness (mm)	Grain diameter (mm)	Thickness (mm)
Medium-grain sand	2–4	300	10–20	200	50–80	200
Fine sand	4–8	200	20–30	200	60–100	200
Gravel	15–30	200	50–150	200	–	–

is 60–80 m^3/h. The effective volume of the storage tank is 50 m^3, at 25 m above the ground. The waterworks provide water continuously. When the demand is less than pumping-station capacity, excess water is stored in the tower; when the demand is greater than capacity, the storage tower and pump together supply the water required. When the consumption is low at night, the pumping station stops working and the storage tower alone supplies the community.

Infiltration Galleries

An infiltration gallery is a horizontal water-collecting facility laid in a riverbed (or riverbank or island in the river). Water is collected through

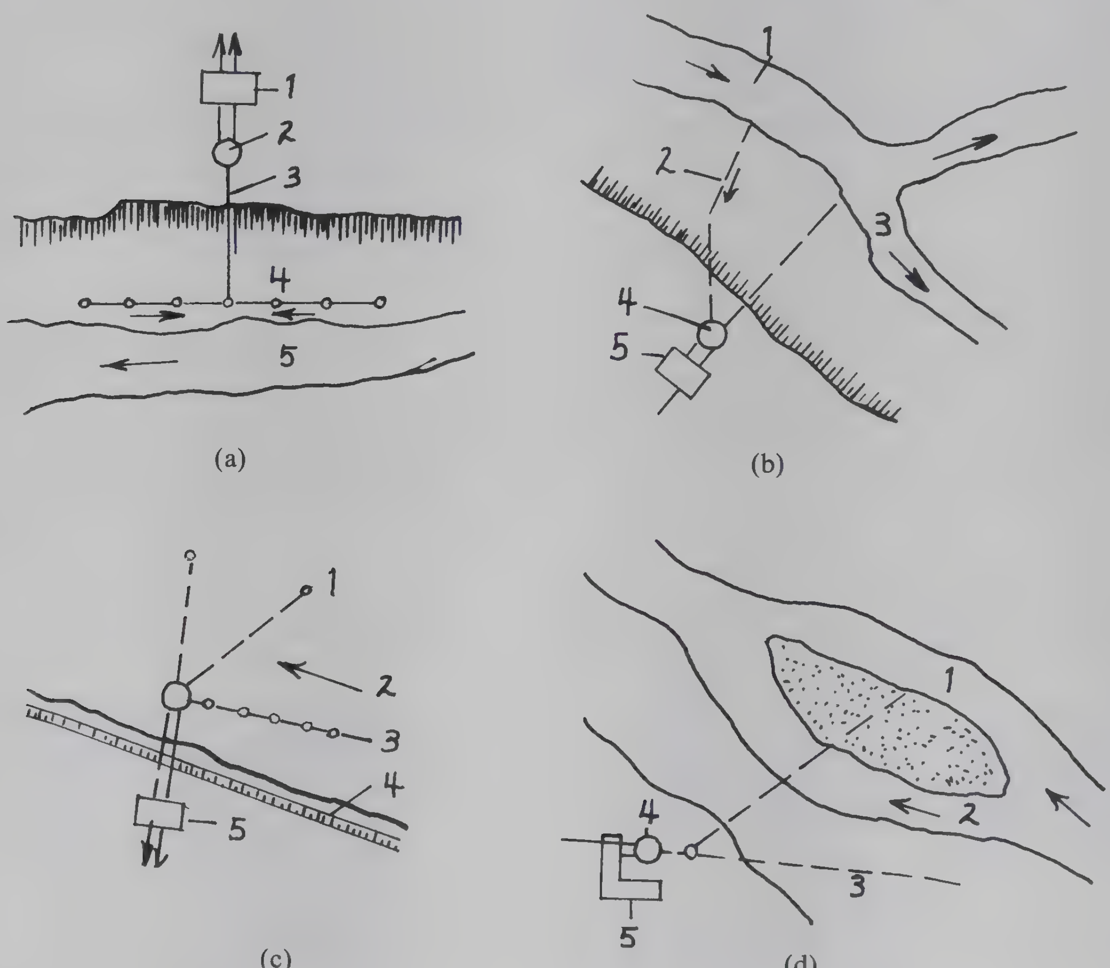


Fig. 24. Infiltration galleries (a) parallel to the river, beneath the riverbank (1, pumping station; 2, water-collecting tank; 3, pipeline; 4, infiltration galleries; and 5, river); (b) perpendicular to the river, beneath the riverbank (1, river; 2, infiltration galleries; 3, branch stream; 4, water-collecting well; and 5, pumping station); (c) perpendicular to the river, beneath the riverbed (1, older infiltration galleries; 2, river; 3, newer arch-shaped galleries; 4, riverbank ; and 5, pumping station); and (d) parallel and perpendicular to the river, beneath the riverbank (1, river; 2, branch stream; 3, infiltration galleries; 4, water-collecting well; and 5, pumping station).

holes in the gallery or pipe or through gaps between pipe sections.

Infiltration galleries intercept and collect the water below the riverbed. This method of collection is relatively efficient and the resulting volume of water is large. In addition, some purification occurs, although the amount depends on the original tubidity of the raw water. If a structure for artificial filtration is installed, about 70% of the suspended solids, 70–90% of the bacteria, and more than 70% of the *E. coli* can be filtered out. The choice of a site for an infiltration gallery greatly affects the water output. The flow of water should be rapid, with enough force to prevent sediment from settling on the bed. The chosen section of river should be straight with inverted banks, and the site should be as close to the mainstream as possible. The water-bearing layer should be thick with no impervious layers within it. The river should have a stable bed, with relatively clean water and little variation in water level. There are four possible configurations (Fig. 24) for infiltration galleries:

- In the first, the galleries are parallel with the river (or at a slight angle) (Fig. 24a); this is suitable for places where the water-bearing layer is thick and groundwater is abundant. The riverbed should be stable and the water of good quality. This arrangement collects the water filtering into the river and groundwater from the riverbank.
- In the second and third arrangements, the galleries are perpendicular to the river beneath either the riverbank (Fig. 24b) or the riverbed (Fig. 24c). The latter is appropriate when there is a thick water-bearing layer and little water under the bank. The percolation of the bed should be good and groundwater abundant. The galleries are placed beneath the riverbed in areas where the rivers are shallow and iced over during winter or where the water-bearing layer is thin and the percolation is low.
- The combination of parallel and perpendicular galleries (Fig. 24d) suits areas where the groundwater is abundant and the water-bearing layer is thick. This arrangement permits collection of groundwater from both the riverbank and the riverbed as well as percolation water all at the same time.

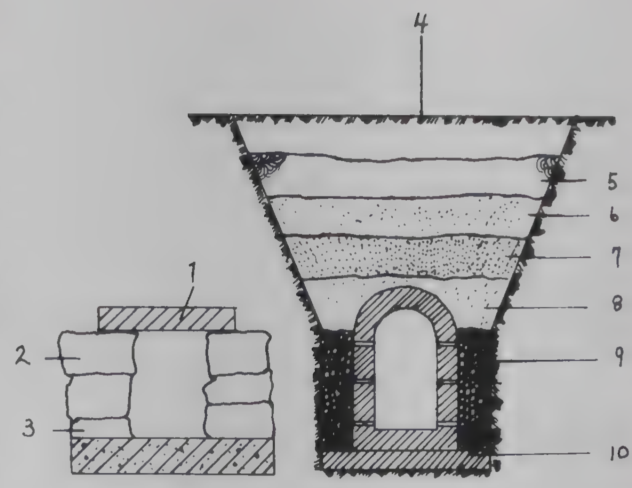


Fig. 25. Materials used in infiltration galleries (1, stone plate; 2, stone blocks; 3, openings, slits, or gaps; 4, surface soil; 5, clay; 6, fine sand; 7, coarse sand; 8, infiltration-sand layer; 9, pebbles; and 10, foundation).

A reinforced concrete pipeline is usually used. If the volume of water is small, steel pipes can also be used. Other locally available materials, such as stone, stone and mortar, or brick (Fig. 25), are also widely used. Sand-filter layers are generally made around the infiltration galleries. The number of layers and their thickness depend on the size of particles in the water, but three to four layers should be sufficient. The total thickness should be 800 mm, with each layer 200–300 mm. The top layer is the thickest but with the finest grain; the layer nearest the galleries should contain grain that is larger than the openings in the gallery piping. There must be no clay, glass, or weathered rock in the layers; therefore, the original sand from the riverbed should be thoroughly washed before being put back as filling.

Chapter 4

Water Treatment

Filtration

Of the many kinds of filters there are two major types based on the filtration rate: slow filters and rapid filters (this publication covers only the former).

Slow filters have a filtration rate of 0.1–0.3 m^3 water volume/m^2 filter area-hour for water below 50 mg/1 turbidity. The inflowing water may be untreated. Water with high turbidity must be pretreated, usually by sedimentation and possibly by coagulation (p. 31).

The disadvantages of a slow filter are its low filtration rate and low capacity; also, it is difficult to clean. Its main advantages are that it removes bacteria very effectively, produces water of high quality, has a simple structure, and can be built with local materials. For these reasons, slow filters are still widely used for treatment in water-supply installations.

The following slow filters are small, simple to operate, and inexpensive. Even though the quality of water produced after treatment with these filters cannot meet national quality standards, there is still value in using them in rural areas in southern China, as they do improve domestic water and, hence, reduce water-related infections.

Pond-Side Filter

The pond-side filter consists of two parts, the filter and the treated water tank. There are three types, depending on the direction of water flow: vertical (Fig. 26), horizontal (Fig. 27), and vertical/horizontal. In the vertical filter, the water flows into the upper part of the filter, through the sand, and out the bottom. In the horizontal filter, water flows through the sand horizontally; as its name implies, the vertical/horizontal filter is a combination of the two. The filter and the treated water tank are connected. Walls can be made of concrete or cemented brick. The bottom of the filter consists of channeled, porous blocks. There are three or four layers of sand, including the foundation layer: the top layer is fine sand (0.3–1 mm diameter), 800–1000 mm deep; the next layer down is coarse sand (1–2 mm), grains 100–150 mm deep; the next is pebbles (2–8 mm), 100–200 mm; and the bottom is stones (8–32 mm), 100–200 mm. The filter tank is 2–3 m high and the total depth of sand layers is 1.2–1.5 m. Thus, above the sand, a space 0.5–1.5 m is available for inflowing-water storage.

Slow pond-side filters are widely used in rural areas of Nanning prefecture, Guangxi province, Guangdong province, and Hebei province.

The filtration rate is based on 0.1–0.3 m/h flow rate. Based on the current water consumption in rural areas, 40–80 1/person-day, every m^2 of filter will be able to supply water to 60–120 people, provided the waterworks runs 24 hours a day. Because demand peaks at certain times, storage should be approximately 50% of the total volume of daily consumption.

The data obtained by the Department of Health and Epidemic Prevention in Fusui county from seven pond-side filters for production brigades indicate the effectiveness of the system: the degree of coloration was reduced from an average 24.5 to 9.8 (60%); the turbidity (mg/1) from 88.8 to 7.7 (91.2%); the oxygen demand (mg/1) from 10.53 to 3.73 (64%); and the total bacterial count/ml from 4486 to 246 (96.3%).

Tests made by the Department of Health and Epidemic Prevention of Guangdong province also indicated that using the filter significantly reduced colour, turbidity, iron (Fe) and magnesium (Mg) content, total bacterial count, and *E. coli* count. Reductions in turbidity and bacterial count were 93.91% and 90.33% respectively.

In areas where ponds are used as the source for water supply, measures to protect the water include prohibiting (1) the washing of clothes and other items in the pond and (2) the use of private buckets to take water directly from the storage tank, which should be tightly covered. When algal growth occurs, particularly in summer, the addition of bleaching powder may be necessary. Also,

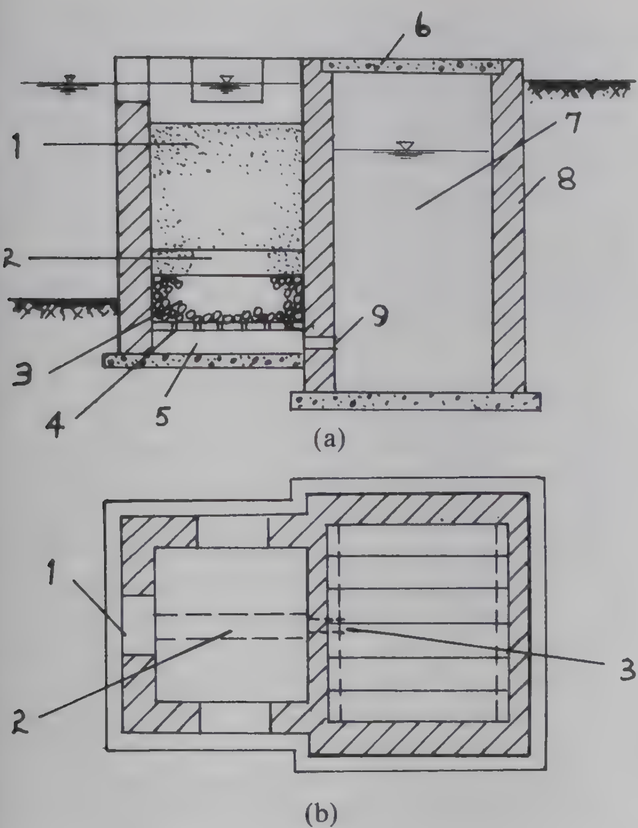


Fig. 26. A vertical pond-side filter: (a) the cross section (1, fine sand; 2, coarse sand; 3, pebbles or stones; 4, channeled, porous stone; 5, main drain; 6, cover; 7, storage tank; 8, wall; and 9, drain) and (b) the plan (1, influent; 2, main drain; and 3, drain).

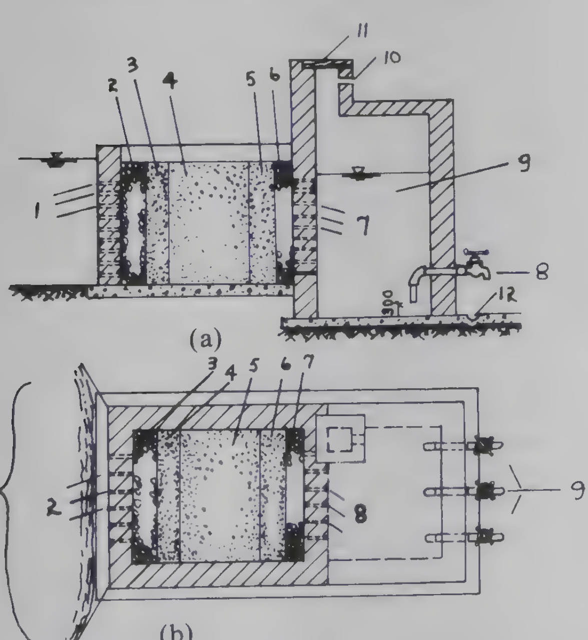


Fig. 27. A horizontal pond-side filter: (a) the cross section (1, drain; 2, pebbles or stones; 3, coarse sand; 4, fine sand; 5, coarse sand; 6, pebbles or stones; 7, drain; 8, tap; 9, storage tank; 10, vent; and 11, cover) and (b) the plan (1, source; 2, drain; 3, pebbles or stones; 4, coarse sand; 5, fine sand; 6, coarse sand; 7, pebbles or stones; 8, drain; and 9, taps).

fish may be put into the pond as a monitor of water quality and harmful contamination.

Depending on the quality of the raw water, periodic cleaning of the 100–200 mm fine sand on the filter surface is needed. The sand is withdrawn and washed about every 1–2 months. The frequency of this washing is determined by the turbidity of the raw water. When the difference between inflow and outflow (head loss) is greater than 1 m or when the treated water is unsatisfactory, washing is necessary. All the sand should be washed every 1–2 years.

Sources of water are selected for their convenience for the users, but a more important criterion is that the raw water be unpolluted and of good quality. Thus, there should be no latrines, manure piles, or grazing areas nearby. Also, experience has shown that using private buckets to take water directly from a water source seriously pollutes the water; effective protection is provided by the installation of hand pumps or taps. In Guangxi, the data from 11 storage tanks showed that the total bacterial count was reduced by 96.2% when hand pumps or taps were used, whereas only 54% reduction was achieved when private buckets were used. Ventilating the storage tank reduces any odours in the water.

Nabu production brigade in Guangxi province has a population of 535 116 households. The brigade's water-treatment installation is a combined horizontal/vertical pond-side filter (Fig. 28). The tanks are stone. The primary (horizontal) filter is 1.5 m wide, and the secondary (vertical) filter is 2.0 m × 2.5 m. There are eight taps at the bottom of the storage tank. The raw water has 25.0° coloration, 100 mg/l turbidity, 5.79 mg/l oxygen demand, and a total bacterial count of 4000/ml. Using the pond-side filtration system, the brigade improves those figures to 10.0°, 6 mg/l, 5.03 mg/l, and 120 bacteria/ml respectively.

In another commune in Guangxi province, a horizontal filter was built out of bricks with the filter in front and the storage tank behind. The taps were placed at the front end of the storage tank. Elsewhere, long, tunnel filters have been constructed of stone and filled with sand. They have functioned well, but the shape has made it difficult to wash the sand.

Washing the sand is labour-intensive and time-consuming. Usually, 5–7 work days are required for a single washing, although this can be reduced by use of a backwash tank (Fig. 29). The steps in using a backwash facility are to close the drain between the storage tank and the filter; open the valve to let the wash water come up through the filter;

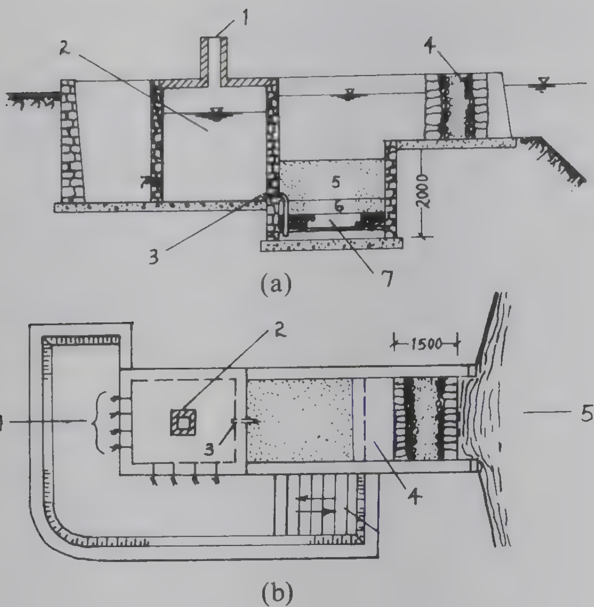


Fig. 28. Horizontal/vertical pond-side filter used by Nabu production brigade: (a) the cross section (1, vent; 2, storage tank; 3, drain; 4, primary filtration; 5, fine sand; 6, coarse sand; and 7, stones or pebbles); and (b) the plan (1, taps; 2, vent; 3, steps; 4, bridge; and 5, source).

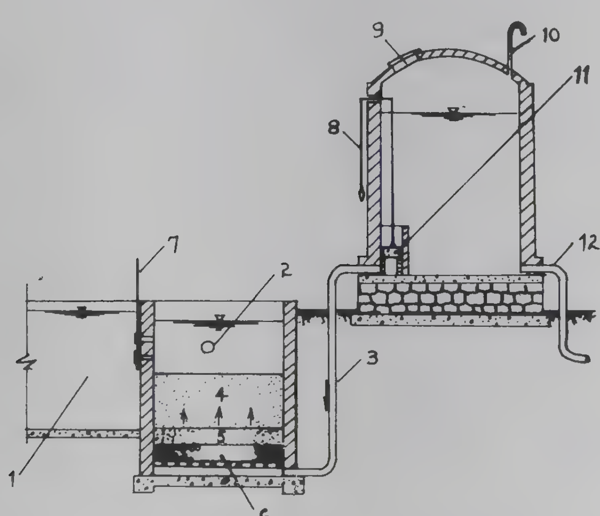


Fig. 29. Simple backwash for slow sand filter (1, sedimentation tank; 2, wash-water outlet; 3, backwash-water inlet pipe; 4, fine sand; 5, coarse sand; 6, pebbles; 7, inlet control sluice board; 8, hand pull; 9, maintenance access; 10, vent; 11, valve; and 12, distribution pipeline).

rake the sand surface to a depth of 200–500 mm; as the wash water becomes clean, stop the backwashing; and, finally, open the drain again for filtering.

The backwash water-storage tank is usually placed 3–4 m higher than the filter system on the bank of the pond. It should have a diameter of 3–4 m, a depth of 2.5–3.5 m, one or two ventilation holes, and a 0.5 m-diameter maintenance access. When backwashing is in progress, the water depth in the backwash tank should be kept at least 1 m deep, and the connecting pipe should be large enough to guarantee satisfactory backwashing. The wash-water outlet should be at least 0.5 m above the sand surface so that the risk of sand losses is minimized.

Riverbank Filter Wells

People living near rivers have designed riverbank filter wells (Fig. 30) to improve the water quality. This type of well has proved to be both economic and efficient. It consists of a pure-water basin and a filter and is constructed near the bank of a river; its method of operation is similar to that of the pond-side filter. A substantial number of such wells have been built in Guangdong province.

The site for a riverbank filter should be an area where the water is deep and swift-flowing. If the well is constructed in a "dead corner," weeds and other suspended solids will enter the filter. The site should be accessible: within 50 m of the area served. The soil should be suitable for construction, and no latrines, stables, excreta storage, or compost heaps should be within 30 m of the site.

The well has a surface area 1.0–1.2 × 1.0 m and a depth of 1.6–2 m. There are one to three inlet holes in the upper part of the filter, and the bottom of the filter has one to three drains, 15–30 mm in diameter, connecting it with the pure-water storage. Sand for filtration is often taken from the river. The three filter layers (including a supporting layer) are the lower layer, 100–200 mm thick, composed of pebbles (grains of 10–30 mm in diameter); the middle layer, 150–200 mm

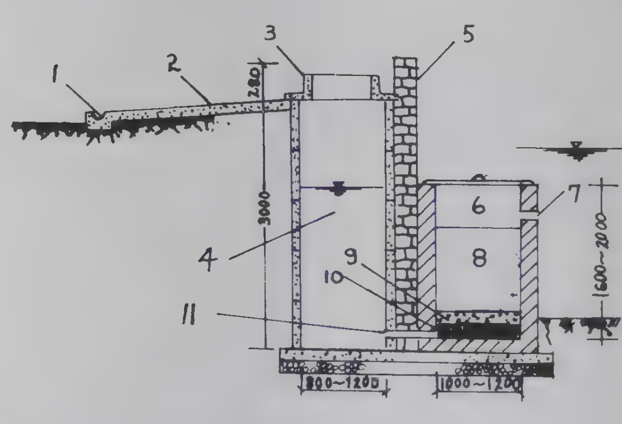


Fig. 30. Riverbank filtering well (1, drain; 2, impervious apron; 3, wall; 4, storage well; 5, protecting wall; 6, filter tank; 7, inlet; 8, fine sand; 9, coarse sand; 10, pebbles; and 11, drain).

thick, of coarse sand (3–10 mm in diameter); and the upper layer, 800–1000 mm thick of fine sand (0.2–2.0 mm in diameter). The diameter of the pure-water storage well reflects the number of users; a 0.8–1.2 m-diameter well can supply 100–200 people (approximately 20–40 households). The well is usually 3 m deep.

Both the pure-water well and the filter can be built of brick or stone; silicate bricks of dimensions 900 × 200 × 380 mm are also used. The materials cost roughly 200 yuan[1].

Water treated by riverbank filtration wells is palatable, without taste or odour. Although it may not conform to national water quality standards, it is a vast improvement on the raw water. According to the statistics provided by Tanbai commune in Guangdong province, where a filtering well was built in 1973, the number of cases of intestinal-tract infections declined by 41.67% from the figures in 1971.

Maintenance procedures for riverbank filter wells are similar to those for pond-side filters. The well should be covered and the bucket used for water extraction should be public property. Regulations should be established to avoid contamination. The surface sand (top layer) should be washed every 2 weeks; the entire filter media and the bottom of the storage well should be washed every 3–5 months; washing is simplest when the water level in the river is low.

Coagulation

A simple process of water purification is sedimentation in which solids settle to the bottom of a container holding turbid water. However, to remove all or even most of the solids, the process takes a very long time. One method to speed up the operation is chemical coagulation of the solids.

The basic concept is to use chemicals (coagulants) to create the conditions for particle conjunction or flocculation. Alum — $Al_2(SO_4)_3 \cdot 18H_2O$ — is the most common coagulant used in China; it reacts in the water to form an aluminum-hydroxide floc. According to the experience of the Shanghai waterworks with alum, the optimum pH for reduction of colour is 4.5–5 and for reduction of turbidity, 6–8; optimum water output is obtained at pH 6.5–7.5. Ferric chloride ($FeCl_3 \cdot 6H_2O$) is also used as a coagulant. It is effective but may corrode metal and concrete. Ferrous sulfate ($FeSO_4 \cdot 7H_2O$) is also used.

[1] Editor's note: costs cannot easily be translated into other currencies because wages in China are low but are supplemented by various allowances and social services.

Chemicals can be fed into water by a solution-feed machine or a dry-feed machine. Practical results show that 10–25% less chemicals are needed if the dosage is introduced into the water before it is pumped through, because thorough mixing will occur by the rotating blades of the pump. The only disadvantage is that the chemicals may corrode the pump over a long period of application.

Disinfection

Water quality improves once the source is improved and protection measures are applied, but there will still be some microorganisms in the water. Investigations have shown that improved wells reduce the total bacterial count by 60–80%; a slow sand filter reduces the total bacterial count of surface water by approximately 90%. To kill the pathogens and bacteria still in the water and prevent the occurrence of water-borne diseases, it is essential to disinfect the water; this is especially true during summer when outbreaks of such infectious diseases are at a peak.

Methods of disinfection are either physical or chemical. Boiling water is one of the former. Most people in rural areas customarily use only boiled water for drinking — a policy that should be more widely promoted. Chemical methods involve the addition of chemicals like chlorine and iodine. Chemical disinfection is effective but leaves an odour in the water. In China, chemical disinfection is now only used in areas with epidemics of intestinal infectious diseases.

Chlorine as an element is a gas with a powerful oxidizing ability. Bleach is made up of chlorine and lime (calcium hypochlorite). It is a white powder with a pungent odour that affects both eyes and nose. Its chlorine content is usually 25–35%. "Refined bleaching powder" is another chlorine compound; it contains 60–70% chlorine.

Bleaching powder, when added to water, produces hypochloric acid (HOCl), which can kill bacteria. The chlorine that comes from bleaching powder in this way is called free, available chlorine. The concentration of bleaching powder required for disinfecting water is usually expressed as the concentration of free, available chlorine.

Besides killing bacteria, chlorine oxidizes some organic and inorganic matter contained in water. Part of the chlorine is consumed in this way, so highly polluted water needs considerable amounts of chlorine for effective disinfection. Different sources and even the same source vary in quality; therefore, the amount of chlorine required should be determined before each application. The exact quantity should be used (Table 5).

Table 5. Bleaching powder consumption of different water sources.

Source of water	Chlorine requirement (mg/l)	Bleaching powder consumption[a] (g/m^3)
Rainwater	0.5–1.0	2–4
Deep-well water	0.5–1.0	2–4
Shallow-well water	1.0–1.5	4–6
Spring water	1.5–2.0	6–8
Turbid river water	2.0–2.5	8–10
Pond water (in a good environment)	2.0–2.5	8–10
Pond water (in a poor environment)	2.5–3.0	10–12
Lightly polluted stored water	2.0–2.5	8–10
Heavily polluted stored water	2.5–3.0	10–12

[a]Bleaching powder with 25% chlorine content.

The treated water should contain a certain amount of residual chlorine (appendices 1 and 2), but excessive amounts produce a strong smell. Generally 0.2–0.5 mg/l will be satisfactory, although heavily polluted water in summer requires more residual chlorine and water in winter needs less.

Well Chlorination

The steps in well disinfection with chlorine are to (1) calculate the water volume in the well (water volume [m^3] = diameter^2 [m^2] $\times$ 0.8 $\times$ depth [m]); (2) determine the bleaching powder required; (3) add a little water to the powder to form a paste and then dilute it; (4) allow any undissolved solids to settle; (5) pour the liquid into the well; and (6) mix the well water. Disinfection takes about 30 minutes, after which time the residual chlorine is measured. When a well is heavily used, the water should be monitored for residual chlorine twice a day, perhaps more often in summer. Table 6 lays out the bleaching-powder consumption for different water depths and well diameters.

In some areas, the plastic-bag chlorinator (Fig. 31a, b) is used for well chlorination. The bleaching powder is placed in a plastic bag in which small openings have been made to allow the chlorine to diffuse. Although this method is simple, its use must be complemented by frequent checks of the residual chlorine. A plastic bag 20 $\times$ 15 cm can hold 300–500 g of bleaching powder. In the bag, there are two rows of small openings, 0.3–0.5 cm in diameter, the upper row above the bleaching powder, the lower row in the powder-containing part. The number of openings depends on the volume of water in the well: 1–2 m^3 of water requires 12 openings on each side of the bag, whereas 3–5 m^3 water needs 13–18 per side. Using these sizes should maintain the residual chlorine at 0.05–0.50 mg/l for 9–15 days. Once the bag is installed, the openings are checked from time to time in case they become blocked.

As an alternative, a bamboo chlorinator (Fig. 31c) is sometimes used. A piece of bamboo about 5–6 cm in diameter, 50–60 cm long with 3–4 small holes (0.5–0.6 cm in diameter) in its wall is filled with 0.5 kg bleaching powder and used the same way as the plastic bag, in the same arrangement, although no flotation rod is necessary. This tool requires little space in the well and maintains the residual chlorine level at approximately 0.2–0.3 mg/l.

Storage-Tank Chlorination

Chlorine solutions for storage-tank chlorination usually need 2–5% free, available chlorine. When a 3% chlorine solution is used, then 5 ml (roughly half a tablespoon) is needed for every 25 litres of water. In areas where the plastic-bag chlorinator is used for chlorination of storage tanks, it is generally 10 $\times$ 4 cm — a bag that will contain 20 g bleaching powder — with three holes (0.3 cm in diameter) on each side, perpendicular to the bottom, 2 cm apart, starting at 1.5 cm from the bottom. The mouth of the bag is tied with an elastic band. Placed in the storage tank, the bag sinks eventually, and the chlorine is diffused. One such bag maintains the residual chlorine at 0.01–0.1 mg/l for 10 days.

Bleaching powder is sometimes combined with ammonia salts — the reaction forming chloramines. Although disinfection takes longer with chloramines than with free chlorine (1 hour as opposed to 30 minutes), the chloramines are stable in water, are effective longer, and do not give off as strong an odour as chlorine.

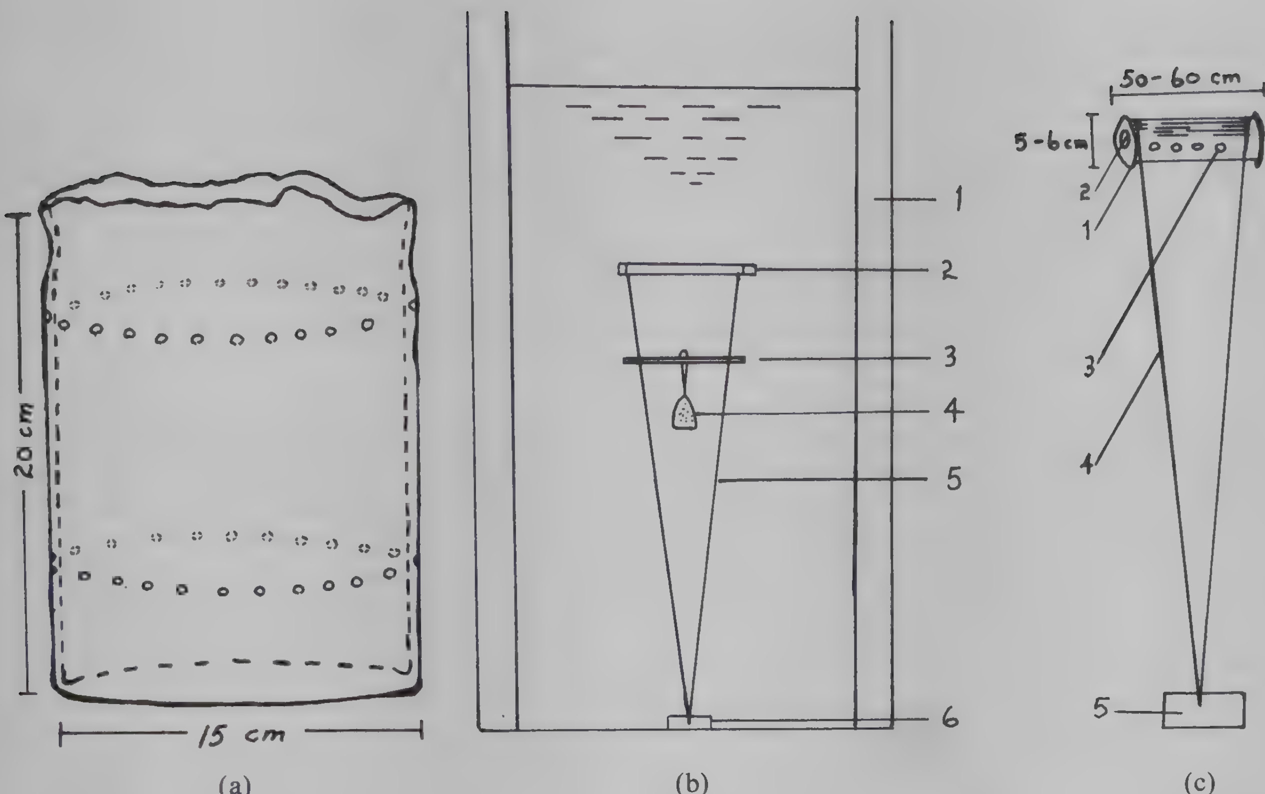


Fig. 31. Two low-cost chlorinators: (a) the plastic-bag chlorinator; (b) in position in the well (1, well wall; 2, floating wooden rod; 3, thin rod; 4, plastic bag; 5, wire; and 6, stone or brick); and (c) the bamboo chlorinator (1, node; 2, opening; 3, hole; 4, wire; and 5, stone).

Table 6. Relationship between the depth, diameter of the well, and the consumption of bleaching powder.[a]

Water depth (m)	Bleaching powder (g) for wells with diameters: 0.5 m	0.8 m	1.0 m	1.5 m	2.0 m
1	1.6	4.1	6.4	14.4	25.6
2	3.2	8.2	12.8	28.4	51.2
3	4.8	12.3	19.2	43.2	76.2
4	6.4	16.4	25.6	57.6	102.4
5	8.0	20.5	32.0	72.0	128.0
6	9.6	24.6	38.4	86.4	153.6
7	11.2	28.7	44.8	100.8	179.2
8	12.8	32.8	51.2	115.2	204.8
9	14.4	36.9	57.6	129.6	230.4
10	16.0	41.0	64.0	144.0	265.0

[a]The required chlorine is 2 mg of bleaching powder containing 25% free available chlorine for each litre of treated water.

Usually a ratio of 4:1 chlorine to ammonia is required for chloramine to be produced, but it can vary. In practice, it has been found that if ammonia is put into the water first and then chlorine, the disinfection lasts longer. If the operation is reversed, some of the chlorine is lost. Ammonium sulfate containing 25% ammonia is commonly used, but ammonium chloride, which contains 32% ammonia is also used. For example, a well with 2 m^3 of water requires 1.5 mg of chlorine per litre of water. If chloramine is to be used instead of chlorine, the required quantities of chlorine and ammonia for a 4:1 ratio are: bleaching powder (20% chlorine) $([2 \times 1.5]/20) \times 100 =$ 15 g and either ammonium sulfate $([1.5/4]2/25) \times 100 = 3$ g or ammonium chloride $([1.5/4]2/32) \times 100 = 2.3$ g. Both ammonium nitrite and ammonium nitrate are poisonous and, therefore, are not used.

Defluoridation

In natural water, fluoride concentrations sometimes exceed 1.5 mg/l and need to be reduced. Effective and simple methods of defluoridation are being investigated, but at present one of three chemical methods is generally used:

- The aluminum oxide method. Burning aluminum at 400–600 °C produces aluminum oxide, which has a high surface area where ion exchange can take place. The aluminum oxide is mixed with the sand used in filtration, and it reacts with the fluoride ions in the water. The filtration rate is

altered according to the concentration of fluoride but generally approximates 2.5 m/h. When treated, if the water still contains more than 1.5 mg/l of fluoride, alum is added and will revitalize the media. This method can reduce the concentration of fluoride from 8.0 mg/l to below 1.5 mg/l, suitable for community water supplies.

- The aluminum chloride method. Alkaline aluminum chloride (0.5 mg) mixed with 1 litre water for 30 seconds reduces the fluoride concentration from 7.0 mg/l to below 1.0 mg/l, suitable for individual or community water supplies.

- The aluminum sulfate method. For every milligram of fluoride ion per litre water, 100–200 mg/l aluminum sulfate are needed for defluoridation. When the raw water has a fluoride concentration greater than 8 mg/l, use of aluminum sulfate alone is not very effective.

Chapter 5

Water Supply Configurations

There is a long history of waterworks in China. People knew the technique of drilling a well to obtain water 4000 years ago. Clarification of water by alum flocculation — still used today — was initiated in China more than a thousand years ago. Since the establishment of the People's Republic of China, great emphasis has been put on the provision of water supplies. All the cities have their own water supply, and many small towns now have water-supply networks. For example, in Zhejiang province more than 90% of the towns have water-supply systems. More encouraging is the fact that many communes and production brigades have been constructing their own systems.

Because water management is directly related to people's health, the Department of Health and Epidemic Prevention is very concerned with water-quality control in rural water supply. Since 1960, for instance, a series of water-treatment works have been constructed in the suburbs of Shanghai as part of the project for schistosomiasis prevention; to date (April 1977), more than 60 waterworks have been built in the Shanghai suburbs alone. In addition, many people who live far from cities or towns have gained access to an adequate water supply. For example, in the Guangxi Zhuang Autonomous Region, Wuming county, several simple water-supply works were constructed after 1967; now 25% of the population of this county is provided with adequate water. Before Liberation, the people of this region only had access to raw surface water. In Jiliang county, Guangdong province, through the use of local methods and local resources in water-scheme construction, more than 110 production brigades now have their own systems, supplying more than 300 000 people.

Since 1965, when Chairman Mao called on the nation's health and medical services to "put the emphasis on the rural areas," the development of water supplies has made considerable progress toward ensuring people's health and, especially, preventing acute water-related infections. For example, in the suburban areas of Shanghai, such diseases were 72.6% lower in 1975 than in 1965.

Water treatment is a means to rid water of water-borne pathogens and harmful substances. Further, it reduces turbidities, colour, taste, and odour to acceptable levels. Water-treatment works should fulfill requirements of quantity, quality, and pressure. Intake works must supply a sufficient quantity of water, whereas the treatment plants improve the water quality. The distribution system moves the treated water to the consumers while maintaining a minimum pressure in the system (Fig. 32).

The sizes of waterworks vary greatly in China; Fig. 33–40 are flowcharts of some systems that are common in southern China and the Shanghai area.

In rural areas, generally, users are scattered over a large area, and rural households are widely dispersed. However, this situation is likely to change with the recent increase of "socialist villages" and the revolution in agricultural production. Currently, the population of a production brigade is 400–800 and that for a commune located in a town is usually between 3000 and 5000. Production brigades use almost all their water for domestic consumption; even in towns where communes are located, more than 60–70% of the water is for domestic consumption. In rural villages, people live together and engage in the same sort of work; therefore the water demand varies greatly during the day, peaking at certain times.

Short periods of breakdown in supply seldom cause serious problems, especially in southern China where surface water is easily accessible. For this reason, it is rarely necessary to have a full-time staff to run rural waterworks. Generally, the leaders of each community run the water-supply system, as well as engaging in the activity of production. There is no clear division of labour, and when the waterworks are being built or extended, most of the community helps; people working for other water-treatment works may also

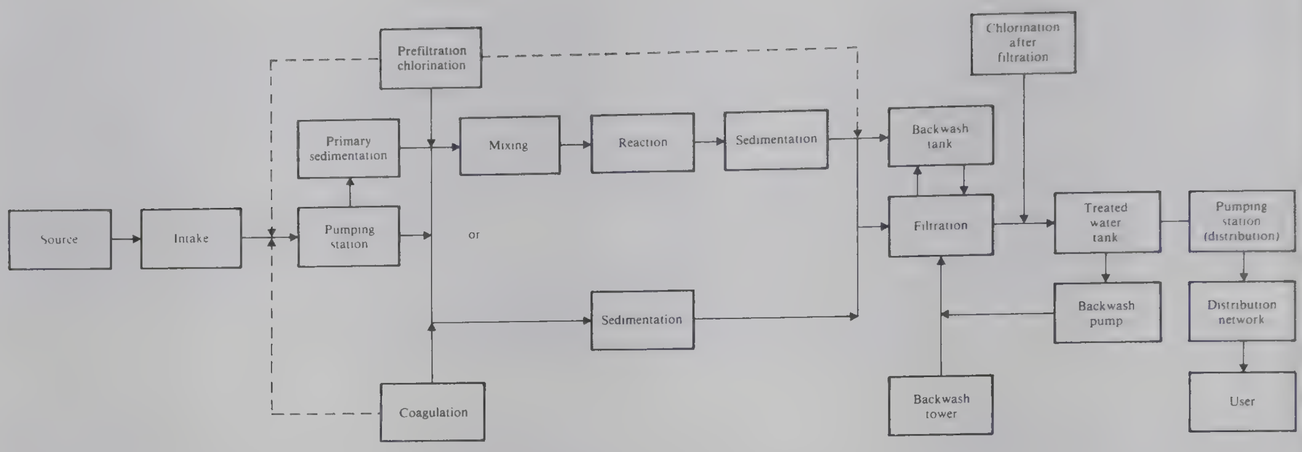


Fig. 32. Surface-water supply.

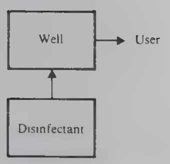


Fig. 33. Suitable system for dispersed populations, each well serving just one or a few households.

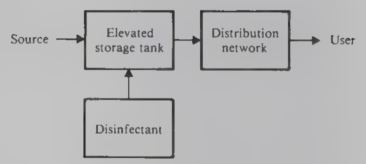


Fig. 34. Suitable system for spring water located at an altitude high enough for gravity feed.

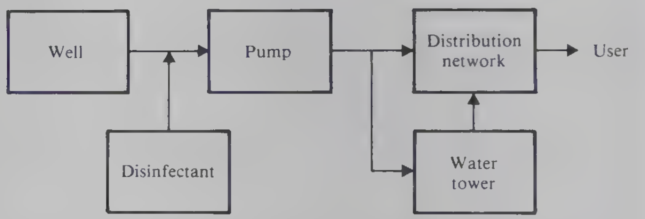


Fig. 35. Suitable system for drilled wells where the water quality is good.

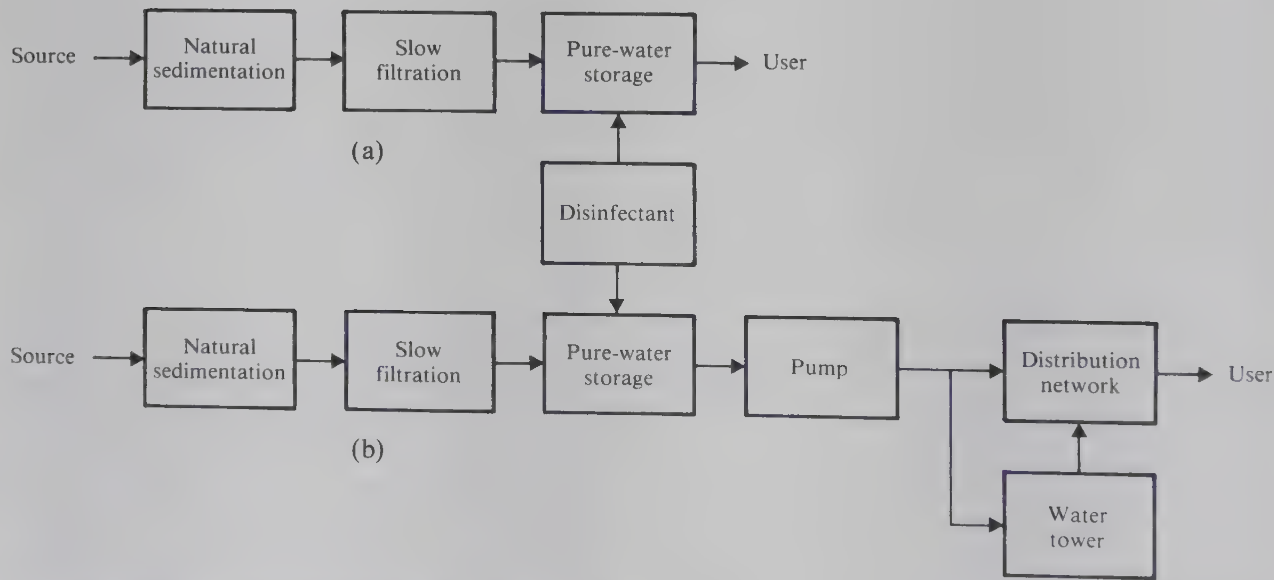


Fig. 36(a) and (b). Suitable systems for surface water: a natural pond usually used for primary sedimentation.

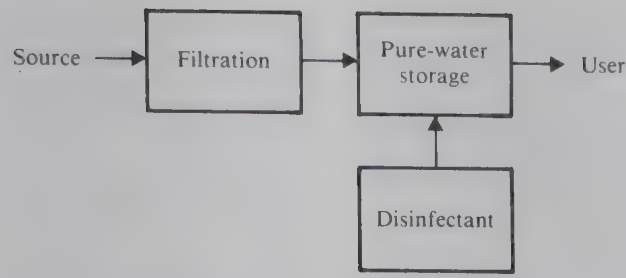


Fig. 37. Suitable system for good surface water, the filtration plant near or next to the source.

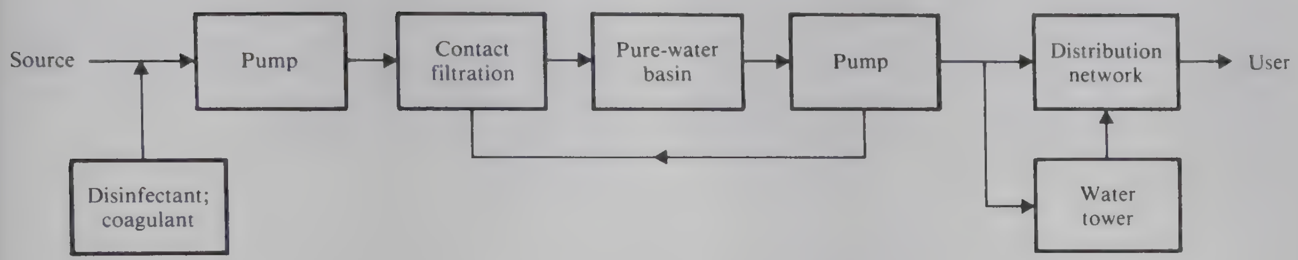


Fig. 38. System suitable for surface water with turbidity less than 100 mg/l.

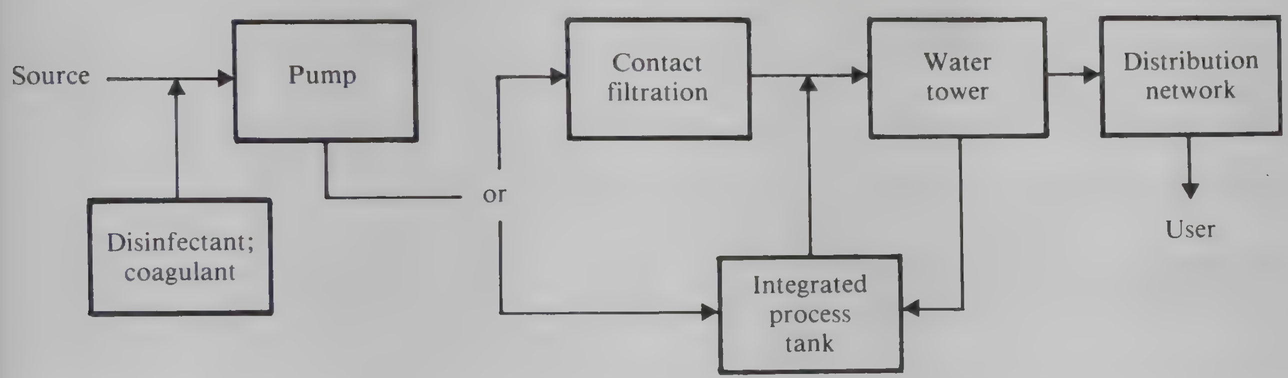


Fig. 39. System for surface water; it includes either an integrated process tank for surface water with a turbidity below 500 mg/l or a direct filtration unit for water with a turbidity below 100 mg/l.

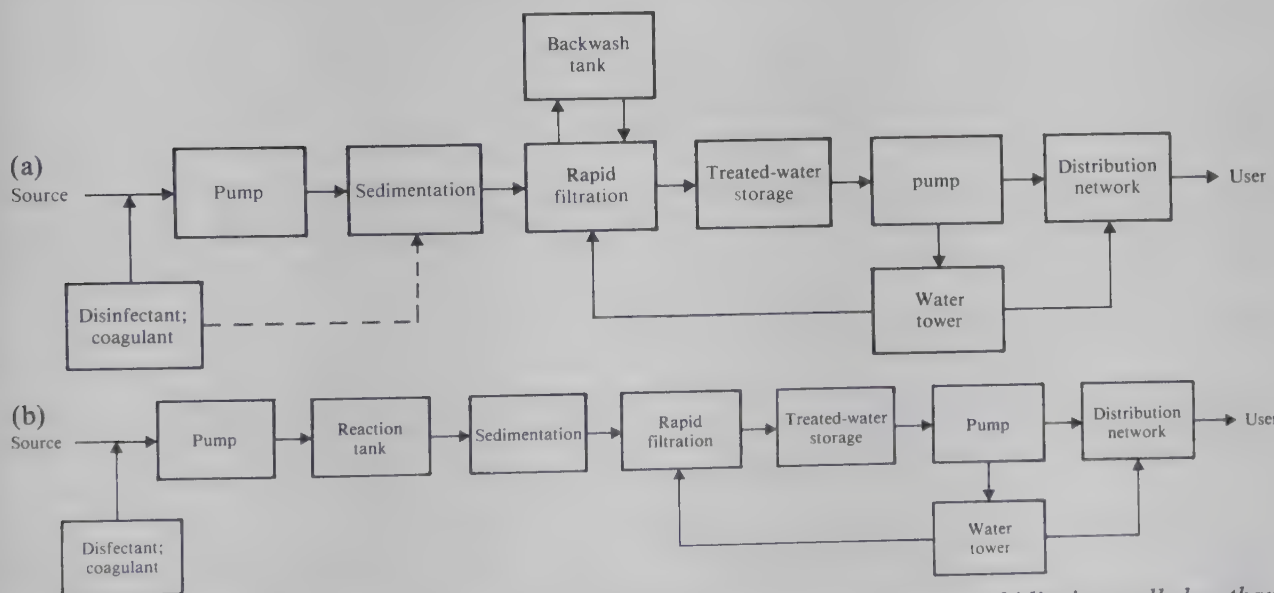


Fig. 40(a) and (b). The most complex systems used in rural China for water supply; turbidity is usually less than 3000 mg/l.

assist. Still, construction, which is based on local methods and materials, sometimes takes a long time.

The communities are encouraged by public health authorities to build as simple and reliable a system as possible. The output of the waterworks is usually less than 24 hours' supply, and storage tanks are generally required. The distribution networks follow a branching pattern.

In construction of the waterworks, the first task is to decide how much water is required, because every component of the system is defined by the volume of water to be supplied. Because China is a huge country encompassing different climates and cultural patterns, water consumption varies greatly across its length and breadth. Water in rural areas is mainly for domestic supplies, and the quantity is estimated on that assumption (Table 7). According to production statistics from 60 waterworks in the Shanghai suburban area, approximately 70–80 litres/person-day are required. In Guangxi province, an estimated 50–60 litres/person-day is assumed for simple waterworks in rural areas. The authority in Fujian province recommends 20–30 litres/person-day for short-term supply and 30–60 for long-term supply.

Besides varying within any day, water consumption in summer is greater than in other seasons, and demand in southern China is greater than in northern China due to differing living customs, climatic conditions, etc.

Table 7. Domestic water demand standard for residential areas.[a]

Outdoor standpipe, no indoor sanitation facilities; with wastewater disposal system.

District (no.)	1	2	3	4	5
Maximum daily consumption (l/person-day)	20–35	20–40	35–55	40–60	20–40
Average daily consumption (l/person-day)	10–20	10–25	20–35	25–40	10–25
Hourly variation coefficient (peak factor)	2.5–2.0	2.5–2.0	2.5–2.0	2.5–2.0	2.5–2.0

Indoor taps, but no sanitation facilities or bathroom; with disposal system.

District (no.)	1	2	3	4	5
Maximum daily consumption (l/person-day)	40–60	45–65	60–85	60–90	45–60
Average daily consumption (l/person-day)	20–40	30–45	40–65	40–70	25–40
Hourly variation coefficient (peak factor)	2.0–1.8	2.0–1.8	2.0–1.8	2.0–1.8	2.0–1.8

Indoor taps, with indoor stanitation facilities but no bathroom.

District (no.)	1	2	3	4	5
Maximum daily consumption (l/person-day)	85–120	90–125	95–130	95–130	85–120
Average daily consumption (l/person-day)	55–90	60–95	65–100	65–100	55–90
Hourly variation coefficient (peak factor)	1.8–1.5	1.8–1.5	1.8–1.5	1.8–1.5	1.8–1.5

Indoor taps, with sanitation facilities and bathroom.

District (no.)	1	2	3	4	5
Maximum daily consumption (l/person-day)	130–170	140–180	140–180	150–190	140–180
Average daily consumption (l/person-day)	90–125	100–140	110–150	120–160	100–140
Hourly variation coefficient (peak factor)	1.7–1.4	1.7–1.4	1.7–1.4	1.7–1.4	1.7–1.4

Indoor taps, with sanitation facilities, bathroom, and central hot water supply.

District (no.)	1	2	3	4	5
Maximum daily consumption (l/person-day)	170–200	180–200	185–215	190–220	180–210
Average daily consumption (l/person-day)	130–170	140–180	145–185	150–190	140–180
Hourly variation coefficient (peak factor)	1.5–1.3	1.5–1.3	1.5–1.3	1.5–1.3	1.5–1.3

[a]Consumption in small public facilities is included, but consumption in sprinkling on roads, in extensive planting projects, and in major public facilities in cities is not. The climatic conditions, distribution system, inhabitants' customs, etc. differ according to locality and cannot be ignored. Applicability to other districts is possible if the climatic conditions, inhabitants' customs, etc. are similar.

Source: Outdoor water supply design regulation (TJ13-74 Preliminary).

The daily coefficient of variation is defined as the maximum daily demand (volume) divided by the average daily demand (volume). According to estimates, the daily coefficient of variation for cities and towns ranges from 1.1–2.0 to approximately 2–4; it is sometimes even greater in rural areas. From the daily coefficient of variation and average daily consumption, the maximum daily volume can be calculated and used as the basis for the various parts of the structure. The maximum volume of daily supply for a waterworks is equal to the number of users $\times$ average consumption per person-day $\times$ daily coefficient of variation. For example, a commune with a population of 3000 consuming an average 50 litres of water per person-day and having a daily coefficient of variation of 3.0 needs a maximum volume of daily supply of 450 m^3/day ($3000 \times 50/1000 \times 3$). Thus the waterworks in this commune should be able to provide 450 m^3/day. However, this calculation excludes factors such as leaking, and the actual consumption would probably be greater than that calculated. Any industrial water consumption also has to be added to the calculation's result.

The use of water in a community fluctuates every hour in the day. The ratio between maximum hourly use and average hourly use during the day is defined as the hourly coefficient of variation. This coefficient for cities and towns may range from 1.3 to 2.5; for communes it may range from 4 to 6. The hourly maximum consumption determines the diameter of the main distribution pipe, the capacity of pumps, etc. The maximum hourly consumption is equal to the maximum daily consumption average per hour $\times$ the hourly coefficient of variation. If the commune in the last example had an hourly coefficient of variation of 5, then its maximum hourly consumption would be 93.75 m^3/h ($450/24 \times 5$).

Chapter 6

The Well Site

When rain and other forms of precipitation fall on the ground, a portion becomes surface water that flows along the ground into rivers and is eventually discharged into the sea; another portion evaporates due to the heat of the sun and is returned to the atmosphere; and the remainder percolates into the ground and accumulates in the water-containing layer, forming underground water (Fig. 41). Underground water can be classified as groundwater, artesian groundwater, and perched water.

Groundwater

Groundwater is the water that collects above the first stable impervious layer of rock. It can move freely, and its surface is known as the groundwater surface. Generally there is no pressure in groundwater; it is supplied mainly by rainwater or the percolation of rivers or lakes. Because groundwater is mainly affected by rain, the level fluctuates greatly, rising during the rainy season and dropping during drought. Groundwater can be used for irrigation in areas where it is plentiful. However, in some places it is scarce and should not be used for irrigation. Village water supplies are often taken from groundwater (Fig. 42).

Groundwater is generally stored in a permeable soil layer. The space between soil particles makes the layer permeable and allows for good water storage.

Artesian Groundwater

Artesian groundwater (Fig. 43) is stored in a water-containing layer sandwiched between and confined by two impervious layers. Geologic variations are such that the upper and lower impervious layers are not continually horizontal. Pressure differentials are located in the water at various locations and form what is known as water heads. If, when a well is drilled, the water flows freely to the surface under pressure, the well is

Fig. 41. Relationship between rain, surface water, and underground water (1, sea; 2, mainland).

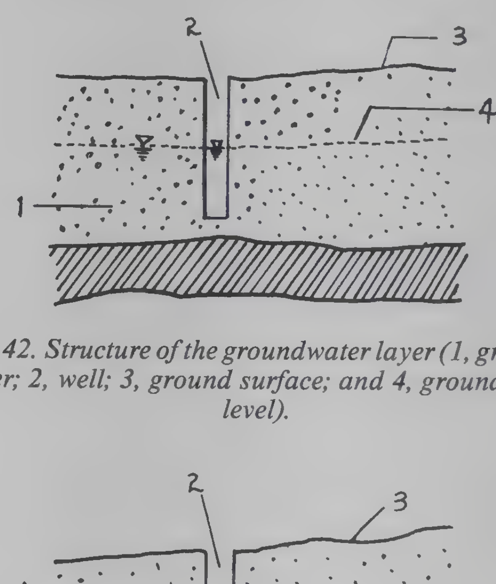


Fig. 42. Structure of the groundwater layer (1, groundwater; 2, well; 3, ground surface; and 4, groundwater level).

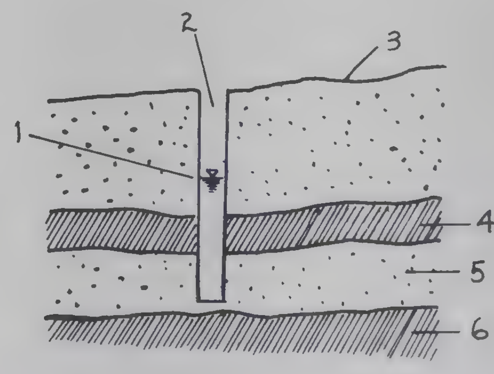


Fig. 43. Structure of an artesian groundwater layer (1, water level; 2, well; 3, ground surface; 4, impervious layer; 5, artesian groundwater; and 6, impervious layer).

known as an artesian well (Fig. 44). If the water rises but does not reach the ground surface it is termed subartesian water.

There is one other type of nonartesian groundwater: water that is sandwiched between two impervious layers but does not fill the water-containing layer. This water moves freely and will not rise when a well is drilled into the layer. Most water used for agricultural irrigation is artesian groundwater; the supply varies in different areas, sometimes coming from very far away.

Perched Water

Perched water exists above a sectional impervious layer. It is not widely distributed and is seasonal. It is not discussed in detail here because it is not significant in the drilling of wells for irrigation (Fig. 45).

The Search for Underground Water

Searching for underground water is relatively complicated, especially in mountainous areas, where the work is affected by topographic conditions and geologic structure. However, there is an important principle that can be followed: underground water is similar to surface water, having a tendency to flow to low-lying areas. An investigation can be carried out in various areas having different topographic and geologic conditions to find the source of underground water and its point of discharge and, thus, to determine the best location for a well.

Underground water can usually be found in valleys or basins in areas where the surrounding topography is relatively high because all the underground and surface water in the area flows toward the central valley or basin. If there is an impervious layer beneath the basin or if there is no discharge point for the underground water, an underground reservoir is formed at the centre of the basin.

In an area surrounded on three sides by mountains (Fig. 46), the valley should have large quantities of water because the surface water in streams and underground water flow toward the outlet of the valley.

Underground water can also be found in marshy land where a number of valleys meet. However, the catchment area must be large to provide enough water. If the catchment area is not sufficient — even if the topographic characteristics are ideal — the supply of underground water will not be abundant.

A well that must be drilled in front of a mountain should be located on the alluvial cone (fan) at the valley outlet because most of the alluvial cone consists of sand and gravel layers, with large spaces between particles and, thus, good storage conditions for underground and surface water flowing down the mountain. Away from the alluvial cone, even if water is found, it will not be abundant (Fig. 47).

A search for underground water in a mountainous area should normally be carried out in areas where limestone is abundant and where the geologic structure is relatively matured, such as a fault-fractured zone. As a result of the earth crust's movements, the rock layers have broken and shifted, and the underground water in the water-permeable layer has been cut off. As the layers break, different widths of fractured zones are formed, and the voids in the rocks are thereby increased. As the voids increase, all the underground water that has been cut off in the water-permeable layer flows to the fractured zone and forms a water-containing zone (Fig. 48). Thus, underground water is found in crevices of limestone areas or in underground caves.

If rocks, such as granite, penetrate the water-containing layer, they form a water-retaining wall so that underground water can also be found where the rock wall begins (Fig. 49).

Underground water also generally exists in flat plains, although the amount varies. Areas with plenty of underground water are usually old routes of rivers or areas that have been flooded at some time; these are very permeable and form a good passage for underground water (Fig. 50). To find old river routes or previously flooded areas, one must depend upon local people, who know the history of the area.

Searching for water and drilling wells are undertaken by local inhabitants because they are familiar with the area, available building materials, etc. Water plants (reeds, cow's hair grass, *Scirpus maritimus*) and water animals (frogs and snails) serve as indicators of underground water, as do abnormal phenomena after weather changes such as, in summer, cooler temperatures in one area than in the surrounding areas; in winter, frost in crack lines of the earth or water vapour in the morning; and in dry weather, earth that appears to be damp when all around the ground is cracked and white.

Rational Planning for Wells

Underground storage capacities are always limited, and if they are exceeded by installed

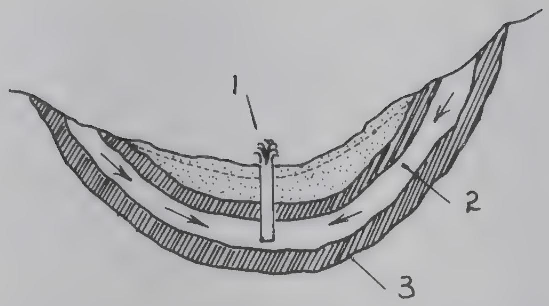


Fig. 44. Structure of an artesian well (1, well; 2, water-containing layer; and 3, impervious layer).

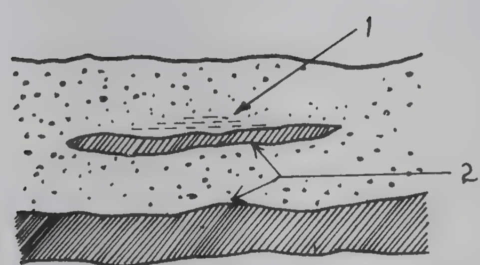


Fig. 45. Perched water (1, perched water and 2, impervious layers).

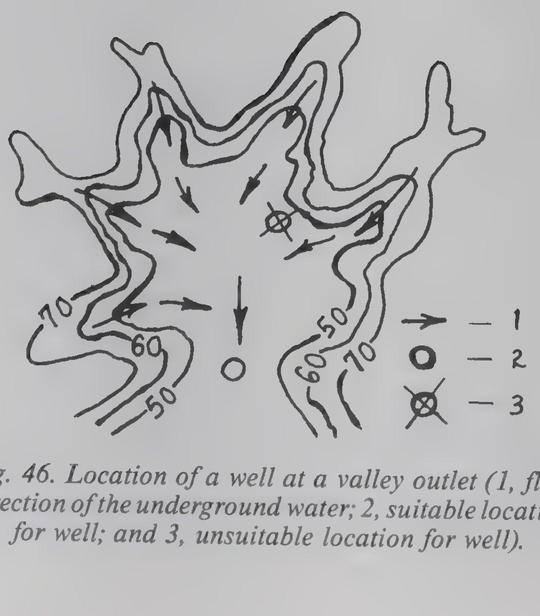


Fig. 46. Location of a well at a valley outlet (1, flow direction of the underground water; 2, suitable location for well; and 3, unsuitable location for well).

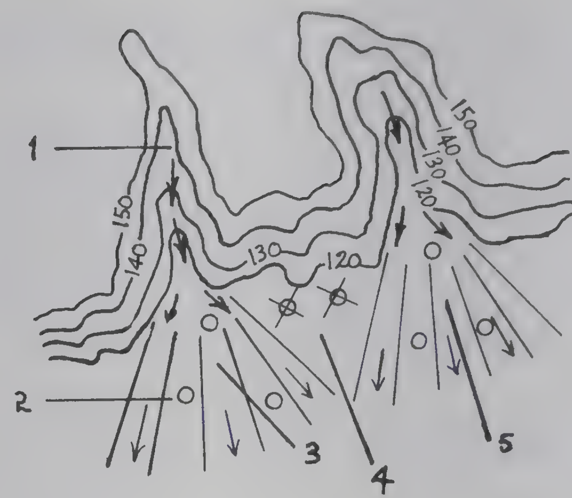


Fig. 47. Location of well on the alluvial cone (1, flow direction of the underground water; 2, suitable well location; 3, alluvial cone, fan; 4, unsuitable well location; and 5, alluvial cone, fan).

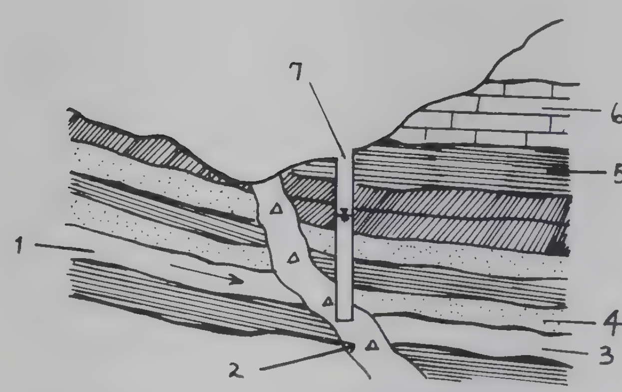


Fig. 48. A fault-fractured zone (1, water-containing layer; 2, fault-fractured zone; 3, water-containing layer; 4, sandstone; 5, shale; and 6, limestone).

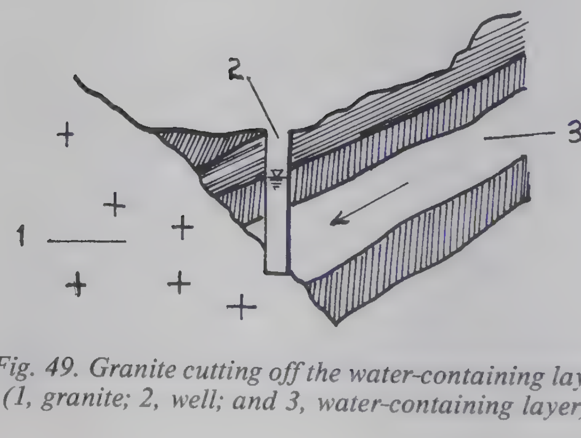


Fig. 49. Granite cutting off the water-containing layer (1, granite; 2, well; and 3, water-containing layer).

Table 8. Characteristics of percussion-drilling machines.

Name, model no. of drilling machine	Production unit	Machine suitable for soil layers	Drilling diameter (mm)	Practical maximum drilling depth (m)	Lifting capacity of reel (t)	Cable standard (mm)	Outer dimensions (length × width × height) (mm)	Weight of main machine (kg)	Power (kW)	Electric motor revolution (rpm)
CJ-700 model percussion drilling machine.	Liaoning Haicheng Agricultural Machinery Factory	Sand; clay; cobble; loose, scattered soil layer; thin slate layer	700	100	1.5–2	18.5	5200 × 1400 × 2300	1400	14	1450
Good-harvest model percussion drilling machine	Hebei Kuan Agricultural Machinery Factory	Loamy soil; gravel soil; sand; loose, scattered soil layer	500	120	1.5	6 × 19 + 1 – 17	1920 × 1280 ×1630	1300	10	1480
150-metres cable percussion drilling machine	Hebei Kuan Agricultural Machinery Factory	Loose, scattered soil layer; thin layer of sandy gravel, sandy cobble	500	150	1.3	6 × 19 + 1 – 17	2030 × 1370 × 1623	1300	10 or 14	1450-1500
Dash and grab drill	Henan Nayang Agricultural Machinery Factory	Sandy soil; cobble; clay; "ginger" rock	1100	33	1.5	12.5–15.5	–	800	7	1500
YKC-30 model percussion drilling machine	Henan Loyang Mine Exploration Machinery Factory	Loamy soil; sandy loamy soil; clay; sand layer; sandy cobble; sandy gravel; weathered rock; half-weathered rock; bedrock, etc.	Last-drill diameter 400	200-250	2.0	–	–	13000	40	–
YKC-22 model percussion drilling machine	Henan Loyang Mine Exploration Machinery Factory	Loamy soil; sandy loamy soil; clay; sand layer; sandy cobble; weathered rock; half-weathered rock; bedrock; etc.	Last-drill diameter 400	150-210	1.3	–	–	7000	28	–
YKC-20 model percussion drilling machine	Henan Loyang Mine Exploration Machinery Factory	Loamy soil; sandy loamy soil; clay; sand layer; sandy pebble; sandy gravel; weathered rock; half-weathered rock; bedrock, etc.	Last-drill diameter 400	120-170	1.0	–	–	5000	20	–

Table 9. Characteristics of rotary drilling machines.

Name, model no. of drilling machine	Production unit	Drilling diameter (mm)	Practical maximum drilling depth (m)	Type of bore head	Machine suitable for soil layers	Boring rod standard (mm)	Cable standard (mm)	Boring rod revolution (rpm)	Power	Maximum weight of drilling machine (t)
ZW-500 counter-circulation well-drilling machine	Province of Jilin Machinery Factory	500	120.5	Tri-wing bore head	Yellow soil; clay; sand; gravel; loose, scattered soil strata	127 × 4.5	Main reel 12.4, secondary reel 9.3	50	NB8 model, 55 hp	–
Anti-drought 66 model manpower rotary drilling machine	Nei Monggol Paotou Agricultural Machinery Factory	1100; 950; 700; 450;	80 (bore diameter 500 mm)	Deer's horn driller	Sandy soil; sandy loamy soil; loamy soil; clay; sandy gravel; cobble smaller than 100 mm	70 × 10	15 × 6 − 1	5	–	–
Twin-well drilling machine	Agricultural Implements Factory; District of Pucheng, Province of Shanxi	700-1100	190 (bore diameter 1100 mm); 120 (bore diameter 700 mm)	Bottom all open	Sand; gravel; cobble less than 50%, diameter smaller than 100 mm	76 × 8	15.5	8	–	–
Sufung 66 model manpower drilling machine	Hardware Factory; District of Fung, Province of Jiangsu	1000-1100; 650-700	67 (bore diameter 650 mm)	Rocket drill	Sandy loamy soil; clay	76 × 8	12.5	–	–	–
R-T65 rotary manpower drilling machine	Agricultural Implements Factory; Province of Shandong	800; 700; 690; 600; 540	101 (bore diameter 450 mm)	Knife's rack driller 110°	Clay; sand smaller than 150 mm; cobble layer	70 × 7	12.5	3-4	–	–
Red-star 300 model drilling machine	Exploratory Machinery Factory; Province of Henan	560	Alluvial stratum 300; Bedrock 250	–	Bedrock; alluvial layer	114	12; 19.5	21; 43; 61; 83 (turning dish revolution speed)	40 kW	10
SPO-30 model drilling machine	Mine Exploration Machinery Factory, Shanghai	500	300	–	Medium-, fine-particle layers	89 × 70 × 6500	6 × 19 + 1 (20, 19.5)	4; 7; 128 (clockwise, counter-clockwise turning dish revolution speed)	Electric engine 40 kW; diesel engine (65 hp)	Main machine weighs 2.3; tripod weighs 5.3; subsidiary implements weigh 4.0
300-metre drilling machine	Machinery Factory District of Pa, Tienchin, Province of Hebei	500	300	–	Clay; sand; weathered shale; clayey, sandy gravel; cobble	73 × 9	–	40 (turning dish clockwise, counter-clockwise)	Concentrated moving power 40 kW	13.2
500 model drilling machine	Agricultural Implements Factory District of Failai, Province of Hebei	500	500	–	Clay; sand; weathered shale	73 × 9	–	65 (turning dish revolution speed)	Concentrated moving power 40 kW	9.8

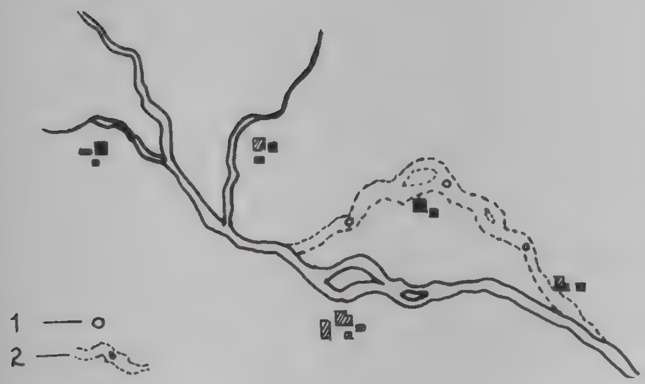


Fig. 50. Layout of an old river route (1, well position and 2, old river route).

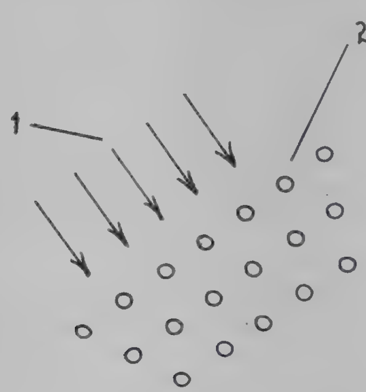


Fig. 51. Arrangement of wells on underground water site (1, flow direction of the underground water and 2, well locations).

pumping capacity, the underground water level drops, the amount of water discharged from the well decreases, and the well may fail. At worst, the underground water level drops to such an extent that the well has to be abandoned. Therefore, in developing and using underground water supplies, one must carefully plan the distribution of wells, the distance between them, and their depth.

Planning must be carried out by a hydrologist and geologist who are familiar with local conditions. An integrated search is carried out on the basis of hydrologic and geologic information or data from existing wells. When hydrologic and geologic data are lacking, a few test wells can be drilled initially and the number increased after observation. If the test wells are arranged in rows, they must be located along the direction of flow of the underground water (Fig. 51).

The location of wells, the distance between them, and their depths should be based on the capacity of the underground-water supply and on the potential effects of lowering the underground-water level. Other items that must be considered are agricultural plans, the level of mechanized cultivation, drainage systems, crop distribution, water and electrical supplies, and transportation during well construction.

The distance between adjacent wells is especially important because interference between wells should be avoided. For example, in an area where there is only one water-containing layer consisting of coarse aggregates such as sandy gravel and rock, wells discharging 3000–4000 m^3/day should be separated by a distance of 300–350 m; in an area where there are several water-containing layers consisting of coarse and medium particles (e.g., coarse and medium sand), wells discharging 2000–3000 m^3/day should be 400–450 m apart; and, finally, in an area where there are a number of water-containing layers of medium, fine, and powder-sized particles, wells discharging 1000–2000 m^3/day should be 500–550 m apart. Single water-containing layers are fairly rare; most areas contain several layers that are best utilized by a combination of deep and shallow wells. This setup ensures that all the water is not taken from one water-containing layer.

Once the location for a well has been decided, the shape of well and the type of drilling machine are selected on the basis of the geology of the area, financial constraints, available construction materials, and personnel.

Usually, wells are 30–150 m deep, although some exceed 200 m in depth. Drilling equipment primarily consists of mechanically and manually driven rotary bores and percussion drilling machines (Table 8 and 9).

The rotary bore is normally used for deep wells in bedrock, in areas where underground water is not abundant in the shallow layers of rock, or in an area where the underground water must be extracted from a deep layer. In riverbeds, where groundwater is abundant, wells are generally dug by hand, and because the workers must climb into the hole to dig, these wells tend to be large.

In mountainous areas, the underground water is normally relatively deep because of the thickness of the covering layers. For this reason, rotary bores and percussion drilling machines are generally used to dig the well, although manually excavated wells are possible if safety measures are followed. In flat or plains areas where water-containing layers are numerous, either manual or mechanical devices can be used for the drilling. The walls or casing for the well can be iron, concrete, cement/gravel, asbestos/cement, or brick pipe. A large-diameter, power-driven rotary bore should be used when the underground water is deep, and the casing of the well should be either cast-iron or concrete pipe.

Chapter 7

Percussion Drilling

Site Investigations

The well-drilling unit sends personnel to a site to carry out investigations and to make necessary arrangements that include:

- A study of the construction site, topography, roads, bridges, etc., to determine the route for transporting the drilling machinery and to arrange for any necessary repairs on roads and bridges;
- A study of local water supply so that adequate water is available during construction work and drilling;
- The preparations for excavation of the slurry discharge pit and its discharge path;
- A study of the electrical supply and the capacity of the transformer to ensure the power requirements of the drilling rig;
- An investigation of the quality of soil; and
- Arrangements for accommodation of the construction workers.

Then, the construction crew are briefed on the tasks to be done.

Drilling Technique

When the drilling machinery has been sent to the field, it is installed on the site and leveled. The mast is raised, and the towline pulled tight and anchored. Every part of the drilling machine is examined carefully, especially the wheel on top of the mast, and all turning parts are oiled. Then, the machinery is given a test run, the bit allowed to move up and down several times as a check on the functioning of the bit and the brake. Using the stationary position of the bit as the centre of a circle, the crew excavate the opening of the well, install a protective pipe, and cover the well opening with planks.

Boring or Drilling

After commencing drilling, all the workers must concentrate on the operation, use their hands to hold the cable so that they can feel the changes of soil-layer characteristics and avoid accidents. The well opening must be covered with protective planks during drilling; otherwise workers or tools may fall into the well hole. Small holes must be drilled in the middle two covering planks for the cable and for regular observation of any changes of position in the cable. Also, the covering planks must be stationary so that the drilling machine is kept in a horizontal position, producing a perfectly perpendicular hole.

The bore-bit should be measured during drilling as an indication of the degree of wear and tear on it and the need for repairs. The hole must be kept circular and vertical during drilling. Every 20 m it must be checked; measurements should be taken on the length of the bore-rod and the angle of deviation of the hole; if there is any deviation, it should be rectified immediately. Whenever drilling is stopped, the drilling machine should be lifted slightly or taken from the hole so as not to become buried.

The well diameter should be wide enough to accommodate filter materials after the pipe casings have been lowered into the well (the thickness of the filter materials should not be less than 10 cm). The angle of deviation for the finished well should not exceed one in a thousand (e.g., if the well is 100 m deep, the deviation should not exceed 10 cm).

Soil samples should be taken during drilling when, through the cable, one can feel that the soil layer has changed. Sampling and recording are important tasks in well drilling. How does one perform them? The old method of sampling is to use a sand-extracting bucket or the bore-bit to bring up the rock and sand samples for examination. However, this method is not accurate, especially in sand, when samples are taken from the water-containing layer. Water washes away the fine particles, leaving only the coarse sand. Thus, the sample is misleading and could result in a wrong judgment.

Now, the sampler shown in Fig. 52 is commonly used. It is lowered to the bottom of the hole

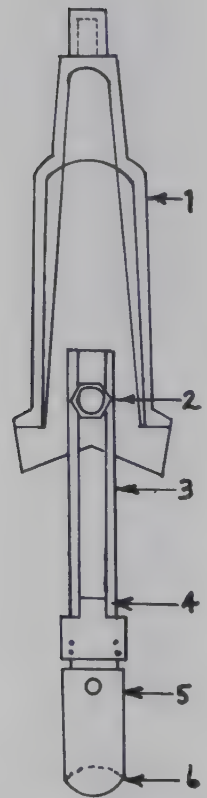


Fig. 52. Soil sampler (1, bore-bit; 2, screw; 3, percussion-sliding tube; 4, impact receiver; 5, water-discharge outlet; and 6, cutter).

so that the sampler's cutter touches the soil layer where the sample will be taken; the bore-bit's cutter is connected to the impact receiver of the sampler; it then hammers the sampler several times and lifts it up. This method of sampling is more accurate than the old method because the sand or rock sample is intact. Samples should not weigh less than 1.5 kg; they should be taken at 4-m intervals in the nonwater-containing layers and at 1-m intervals in the water-containing layer. The samples should not vary more than 10 cm in depth.

At each layer, a soil sample should be taken and its description recorded. It should be stored in a wooden box and be identified by a number, description, depth, thickness, etc. The drilling log (Table 10) should record a description of the soil, the depth and thickness of each characteristic; it should be drawn to scale and should follow standard geologic symbols (Fig. 53). The drilling log should be kept current as the work progresses.

Soil samples are the most reliable means available to monitor drilling; however, distinguishing a soil sample, as well as classifying it, is a subjective process; it can be made as consistent as possible if the people performing it are aware of existing standards in discrimination and terminology.

The clay group includes clayey sand, sandy clay, clay, loess and loessy sand, artificial soil, planting soil, peat, and silt.

Clayey sand: Mainly sand, this type of soil, when rolled between a person's hands, feels very sandy; also it can be rolled into a 3-mm thick rod, though sometimes the rod is difficult to form. Water seeps out when this type of soil is saturated, and it can be easily crushed; when dry, it forms a lump, albeit a very fragile one, and in water, it disperses.

Sandy clay: Mainly clay, this type of soil feels slightly sandy when rubbed between a person's hands; it can be rolled to form a 1–2-mm thick rod; after being cut with a knife, this type has a cut surface that is slightly smooth and bright. It is very hard when dry.

Clay: This type of soil does not feel sandy at all; it can be rolled into a long rod having a diameter smaller than 0.5 mm. After being cut with a knife, this type has a cut surface that appears very bright. It is very hard when dry.

Loess and loessy sand: When rolled between a person's hands, this type of soil has a floury texture, rather than a particle-like texture. Having a greater void in structure, it loosens easily.

Artificial soil: This type of soil has been disturbed by human beings; it is mixed with construction rubbish, broken brick, tile, etc.

Planting soil: This type of soil is topsoil and contains plant roots.

Peat: This type of soil is black, has a high moisture content; when rubbed between a person's hands, the decomposed part of peat will squeeze out between the fingers; its volume is reduced when it is dried.

Silt: Grey-black in colour, this type of soil resembles decomposed peat, but it contains some minerals and has a distinct smell. It is hard when dry.

The sand and rock group comprises boulders, bulk rock, pebbles, debris, conglomerate, gravel, coarse sand, medium sand, fine sand, powdered sand, and ginger rock.

Boulders: This type of soil mainly consists of rounded rock fragments having a diameter greater than 200 mm and a weight exceeding 50% of the total soil sample.

Bulk rock: This type mainly consists of subangular rock fragments having a diameter greater than 200 mm and a weight exceeding 50% of the total soil sample.

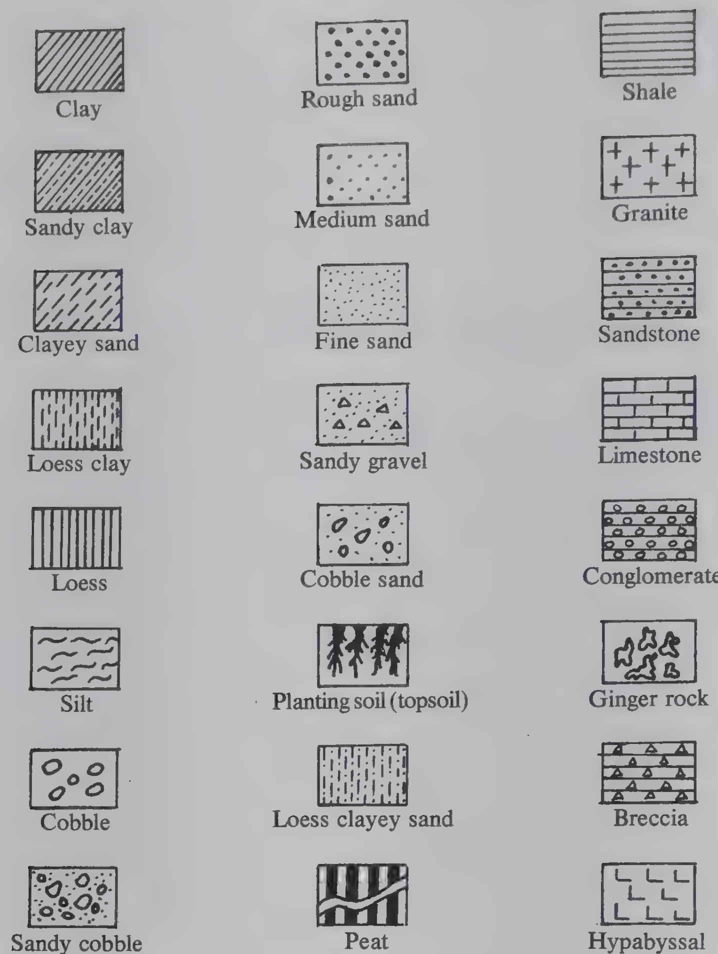


Fig. 53. Geological symbols.

Pebbles: This type mainly consists of rounded rock, with a diameter greater than 10 mm and a weight exceeding 50% of the total soil sample.

Debris: This type mainly consists of subangular rock, with a diameter greater than 10 mm and a weight exceeding 50% of the total soil sample.

Conglomerate: This type mainly consists of rounded and subangular rocks having a diameter greater than 2 mm and a weight exceeding 50% of the total soil sample.

Gravel: This type is made up of rocks with a diameter greater than 2 mm and a weight exceeding 25% of the total sample.

Coarse sand: The diameter of the constituents is greater than 0.5 mm and their weight exceeds 50% of the total sample.

Medium sand: The diameter of the constituents is greater than 0.25 mm, and their weight exceeds 50% of the total sample.

Fine sand: This type of soil has 70% or more of its weight composed of particles with a diameter greater than 0.1 mm.

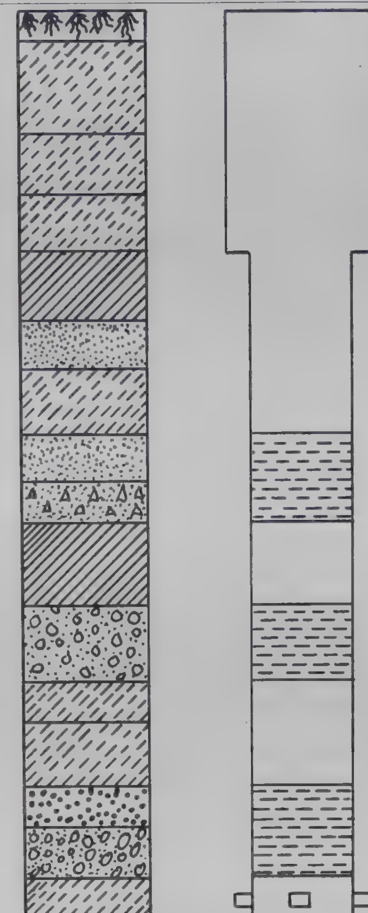
Powdered sand: This type of soil has less than 70% of its weight made up of particles with a diameter greater than 0.1 mm.

Ginger rock: The shape of this type resembles green ginger.

Slurry is a mixture of water and clay. Using slurry while drilling prevents cave-in, suspends debris, and allows safe penetration of sand layers. Proper use of slurry ensures safe drilling; however, if slurry is used excessively, it hinders washing of the well and adversely affects the quantity of well discharge. Therefore, the consistency of the slurry must be varied according to the characteristics of the soil layer. The quality of the slurry is a reflection of specific gravity, density, viscosity, amount of sand, cohesiveness, stability, and permeability. Although permeability

Table 10. Sample of drilling log sheet

Depth to layer (m)	Thickness of layer (m)	Water-containing layer	Geological symbol	Structure of well tube	Filter materials (mm)	Depth (m)	Filter pipe	Description
0.50	0.50							Top soil
8.00	7.50							Yellowish brown clayey sand
13.00	5.00				4–6			Gray clayey sand with decomposed wood debris
19.00	6.00							Gray clayey sand
29.00	10.00							Yellowish brown clay
32.50	3.50							Fine sand
42.00	9.50					44.51		Yellow clayey sand
45.00	3.00				2–3			Fine sand
48.30	2.60					48.58		Sandy gravel
61.60	14.00				4–6			Gray clay
74.10	12.50				3–4	74.81		Sandy cobble
75.60	1.50							Clayey sand
85.10	9.50				4–6	81.91		Gray clayey sand
86.80	1.70							Medium sand
92.10	5.30				2–3	89.45		Sandy cobble
94.00	1.90				4–6			Yellow clayey sand



Serial no.	65-2-05	**Underground water layer (m)**	11.5	**Method of joining**	Screw joint
Drilling unit		**Type of drilling machine**	YKC-20	**Date of construction**	2 January 1968
Location	50 m north of Chan Village	**Method of drilling**	Percussion	**Sand content**	
Well diameter at opening (mm)	500	**Type of well pipe**	Cast iron	**Method of well washing**	Piston

must be measured in a laboratory, all the other parameters can be measured in the field. Specific gravity, viscosity, amount of sand, and cohesiveness should be measured frequently, but if the workers find it too troublesome to determine the viscosity, the specific gravity (the ratio of the slurry's weight to the weight of the same volume of water) can be used as a control for other parameters. Specific gravity can be measured easily, i.e., a hydrometer is dipped into the slurry and the reading taken. The specific gravity of ordinary soil is constant between 1.1 and 1.5, whereas in a sandy-cobble layer or artesian groundwater layer, it is calculated as an average of overall conditions and is generally higher than 1.25. The requirements for slurry are briefly:

- When the slurry's specific gravity is 1.1, the amount of sand it contains should not exceed 5%, and the viscosity should not be slower than 17 seconds; the viscosity meter is shown in Fig. 54;
- The well hole should always be filled with slurry to a level not lower than 0.5 m from ground level. If drilling is stopped, the bore-rod should be moved up and down several times every hour as a means to maintain a uniform concentration of slurry throughout the hole; if necessary, fresh slurry should be added. In a layer where the slurry tends to leak or in an easily collapsible layer, the specific gravity of the slurry should be increased, and the duration of drilling interruptions should be shortened; in fact every possible means should be used to bore quickly through that layer. Unless there is a special need, dry clay or clay balls should not be allowed into the hole;
- In a fine sand layer, the slurry's viscosity should be 18–20 seconds; in medium sand, 20–22 seconds; in coarse sand 22–24 seconds; and in gravel, cobble, or fault layers, 24–28 seconds;
- When testing equipment is not available, one can usually estimate sand content by fingering and handling a sample of the slurry; it is considered suitable when no sand can be felt. One can also test viscosity by using a smooth pole; if very little adheres to the pole, the slurry is considered suitable; and
- When there is a thick layer of clay inside the hole, the slurry can be made in the well itself, water being poured into the hole and being mixed by the movement of the drilling machine. However, after the clay layer has been bored through, the new layer must be tested and slurry added accordingly.

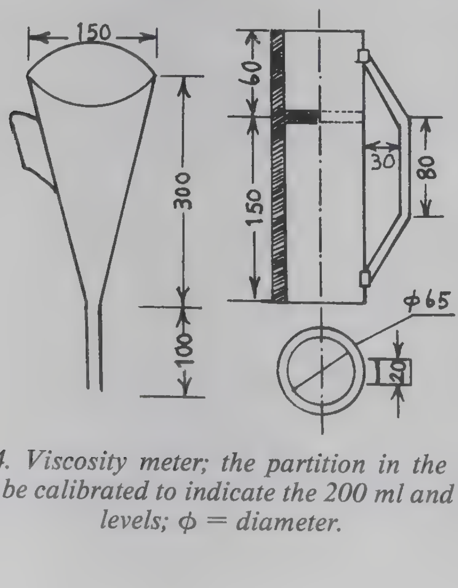


Fig. 54. Viscosity meter; the partition in the centre should be calibrated to indicate the 200 ml and 50 ml levels; ϕ = diameter.

Sieve Analysis

Sieve analysis of the sand sample taken from a water-containing layer can be carried out in the field; it is necessary in determining the correct terminology and in selecting the right filter pipes and filter materials. After drying the sand sample taken from a water-containing layer, one must carry out sieve analysis. There are several commonly used sieves for particle diameters greater than 10 mm; for diameters 10–2 mm, 2–0.5 mm, 0.5–0.25 mm, and 0.25–0.1 mm and for diameters smaller than or equal to 0.1 mm.

The sieves should be constructed so that they can be stacked — the largest-diameter mesh on top — and can be interlocked and shaken without loss of the sample.

The sample should weigh about 1 kg. After the sieves have been stacked, the sand sample is poured into the top sieve, the one with the largest holes. The interlocked stack of sieves is then covered and shaken vigorously. Finally, the particles retained by each sieve are weighed and recorded (Table 11). The results of sieve analysis should be kept as a permanent record of the well.

Well Casings

There are many types of pipe that can be used as casing for a well. The common ones are steel, cast iron, plastic, asbestos cement, clay, brick, and concrete. The suitability of a particular material is determined by the soil characteristics and the financial resources available. The materials all have a fixed strength and porosity (about 15–35%); the smaller the pipe diameter is, the lower the porosity.

After the drilling is completed and before the casing is lowered into the hole, the well should be measured with a hole-testing apparatus that is 50 mm smaller than the internal diameter of the well. This check is to ensure the hole is circular and vertical. A steel ruler is ideal for measuring the diameter.

Table 11. Sample results of sieve analysis.

Sample no.	Sampling depth (m)	Visual description of soil	Distribution (% total weight) of particles with diameters (mm): ≤0.1	0.1–0.25	0.25–0.5	0.5–2	2–10	≥10	Sieve analysis description
1	25	Fine sand	10	50	30	10	–	–	Fine sand
2	34	Medium sand	5	25	45	20	5	–	Medium sand
3	38	Medium sand	4	16	10	65	5	–	Coarse sand
4	42	Cobbly sand	5	15	50	10	15	5	Gravel medium sand
5	57	Sandy cobbles	–	3	7	30	45	15	Coarse sandy gravel

Attention should be paid to the arrangement of the casing and the well-screen pipes; their locations and lengths should tally with the geological symbols of soils on the drilling log (Table 10) and should be arranged in the order in which the pipes will be lowered. The drilling log should provide an accurate picture of the lengths and types of soil layers and, thus, should be a guide to the types and lengths of pipes required. It also indicates the need for filter materials as well as their type and depth.

The filter pipe and filter materials used should suit the conditions of the soil layers. In coarse, aggregate layers such as medium sand, coarse sand, sandy cobbles, or sandy gravel, it is not advisable to wrap the outer filter pipe with coir bark (fibrous leaves matted together), coppermesh, or similar materials. However, in fine and powdered sand layers where the filter materials will not prevent the fine particles from entering the well pipe, a thin layer of coir bark can be wrapped around the outer face of the filter pipe.

The well pipes should meet quality standards; substandard pipes should never be used in wells. All the pipes — well-wall pipes, filter pipes, the settling pipe, and the foundation — should be placed near the hole in the order they are to be lowered. When cast-iron pipe is being used, a circular pipe-testing instrument 5 mm smaller than the internal diameter of the well pipes should be passed through the pipes as a check on whether a piston can be used to wash the well.

The slurry inside the hole must be replaced before the pipes are lowered; the concentrated slurry is pumped out while clear water is being added. The water level should not be lower than 0.5 m from the ground surface; this level must be maintained until all the filter materials have been added. Replacing the slurry with clear water is sometimes tricky because of the risk of cave-in, especially of the easily collapsible layers.

A "straightness-supporting device" (Fig. 55), usually wooden, is tied securely to the base, middle, and upper portions of the pipe, so that the well stands straight in the centre of the hole, and an even thickness of filter materials can be placed around the pipe. The clearance between the straightness-supporting device and the hole wall should be 20–40 mm.

If a screw-joint, cast-iron pipe is used, then the screw joint must be cleaned with a steel brush and the pipe hoop must be tested on the two joined pipes. If the pipe is of another type or the joining method is different, all the components of the joint must be properly prepared. If either a cement pipe or a concrete pipe is used, a suitable composition of joint materials by weight would be 43% bitumen, 43% cement (no. 300 or no. 400), and 14% salt. The method of preparing the materials is to place the bitumen in a pot, heating until it melts and then adding the cement and salt. The mixture is then boiled to pastry consistency and applied to the end of the pipe that has been brushed clean. The ends of the two pipes are aligned, pressed firmly together, and secured with thin, flat strips of bamboo tied around the outer wall of the pipe. The bamboo strips prevent the pipe from going awry when it is lowered into the well. This method is dependable and saves time.

Before lowering the pipe, workers place a pipe-lowering wooden support at the opening of the well and drive in four pieces of fixed wooden piles so that it will stay symmetrical to the opening of the well.

The fixed wooden piles are four pieces of rounded timber, 2 m long and not less than 25 cm in diameter (Fig. 56). An iron hoop with a groove should be fastened to the middle of each piling to protect the timber.

A steel cable is used in pipe lowering; diameters of 12.5 mm, 14 mm, and 15.5 mm are suitable and one end should have a loop. Fig. 56 indicates an iron hook is also necessary, but it is common to use a steel bar with a diameter of 20 mm, a length of 30 cm, with a circular hook at one end.

There are two common methods for pipe lowering: one is to use a pipe stopper to hold the pipe while it is being lowered. This method is suitable for cast-iron pipe, which is lowered in stages. The other method is suitable for cement, concrete, and asbestos cement pipes. The preliminary steps (Fig. 57) are to place the cables for

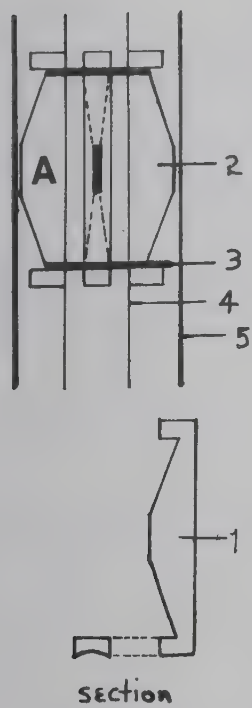


Fig. 55. A straightness-supporting device (1, section A; 2, straightness-supporting device; 3, galvanized wire tie; 4, well pipe; and 5, hole wall).

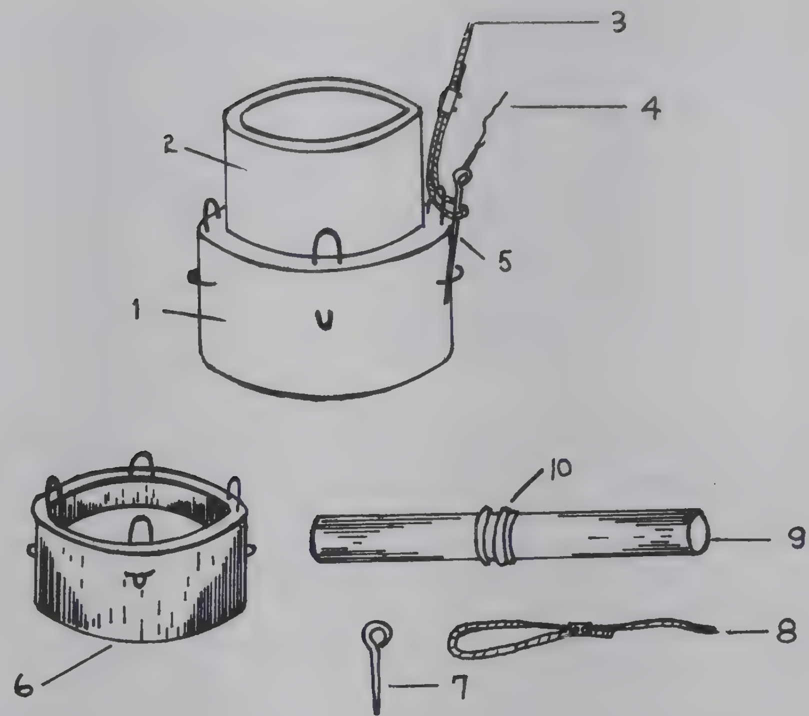


Fig. 56. Pipe-lowering tools (1, base; 2, well pipe; 3, main pipe-lowering cable; 4, secondary cable; 5, hook; 6, base; 7, iron hook; 8, cable; 9, pipe-lowering fixed wooden pile; and 10, groove form iron hoop).

lowering the pipe at the opening of the well, wind one end around the groove of the iron hoops on the fixed wooden piles as a means of control, fix the steel cable loops onto a base with the iron hooks, suspend the base securely over the opening of the well, place the well pipe (usually the sand settling pipe first, the filter pipe next, and finally the well-wall pipe) on the base, fasten the joints with galvanized wire to hold on thin, flat strips of bamboo. Next, the cable is slowly released until the whole pipe is lowered to the bottom of the well.

After all pipes have been lowered into the well, the clearance between the wall of the pipe and the hole must be filled with filter materials that prevent sand getting into the pipe. The choice of filter materials depends on the particle-size of the sand sample taken from the water-containing layer (Table 12). The diameter of the filter materials should generally be 8–10 times greater than the particle sizes in the water-containing layer. The reason is that the physical arrangement of the filter particles is similar to a layer of filter mesh (Fig. 58). The layer of filter particles prevents sand particles in the water-containing layer from entering the pipe and allows the water to flow through. Therefore when selecting filter materials, one must choose well-rounded gravel, not rock debris or other materials. Substandard foreign elements and soil should be removed and should definitely not exceed 10–15%. If the particle sizes of the filter materials are not correct, or there are a lot of foreign elements and soil, then the filter materials will not function properly.

The amount of filter materials should be calculated according to the formula: $\pi(R^2 - r^2)\,h$, where R = well-hole diameter; r = outer diameter of well pipe; h = depth of well hole; and $\pi = 3.1416$. This amount plus 15% should be sufficient.

The opening of the pipe should be covered before filling so that no filter materials enter the well pipe. The materials should be added continuously, gradually, and evenly around the well pipe. If the materials become blocked or arched, an iron bar can be used to pry them loose but the well pipe should not be moved at all. The depth of the filling should be measured periodically, and suitable filter materials (Table 12) should be placed at each water-containing layer. The height of the filter materials should reach 0.7–5.0 m above the height of the water-containing layer. If the water-containing layers penetrated by the well hole are not much different from one another, mixed filter materials can be used. The advantage of mixed materials is that they eliminate the need for repeated measurements and they speed up the process considerably.

In an area where the upper and lower layers are freshwater-containing layers, the space between

Table 12. Relationships between diameter of sand particles in the water-containing layer, filter materials, and filter pipe spacing.

Corresponding sand-particle size in water-containing layer (mm)	Filter materials (mm)	Filter pipe spacing (mm)
0.10–0.15	1.0–1.5	0.75–1.00
0.15–0.25	1.5–2.5	1.00–2.00
0.25–0.50	2.5–4.0	2.00–3.00
0.50–0.75	4.0–7.5	2.00–4.00
1.00–1.25	7.5–12.0	5
1.25–2.00	12.0–18.0	5–7
>2.00	18.0–20.0	7–10

the well wall and the hole should be filled to ground level with filter materials. This procedure facilitates the adding of filter materials if the original material should settle naturally or during well repairs. If the water in the upper layer is undesirable (e.g., saltwater), it should be completely sealed with clay after the filter materials have settled. The seal should begin from 1.0 to 5 m below the layer.

Well Development and Water Testing

Well washing (for well development) is one of the important steps in well-drilling techniques and a key to achieving a good well. It should be done immediately after the filter materials have been added to the hole. Common methods for well washing use a piston, compressor, extractor, or the combination of a piston and a compressor. The purposes of well washing are to remove soil stuck on the wall of the hole, to remove the slurry, to remove any soil in the water-containing layer, and to remove the fine particles in the water-containing layer that are adjacent to the filter materials; this procedure allows the filter materials and the particles in the water-containing layer to arrange themselves naturally and, hence, to form a good underground, water-filter layer. The piston method is applicable to wells in which screw-joint or welded-joint iron pipe has been installed; this method is second only to the combined piston and compressor method. The advantages are that it is highly efficient and that it is thorough, ensuring a good well discharge. Within 2–3 hours washing, the piston method removes the soil stuck on the wall of the well hole and within two or three shifts removes the slurry that has penetrated into the water-containing layers as well as the fine particles. The thoroughness of the method means maximum water discharge. Other methods never achieve this. For example, a well that was being washed by the compressor method only achieved a discharge of 1600 m^3/day whereas when the well was rewashed by the piston method, the final discharge was 2500 m^3/day (under the same water-level condi-

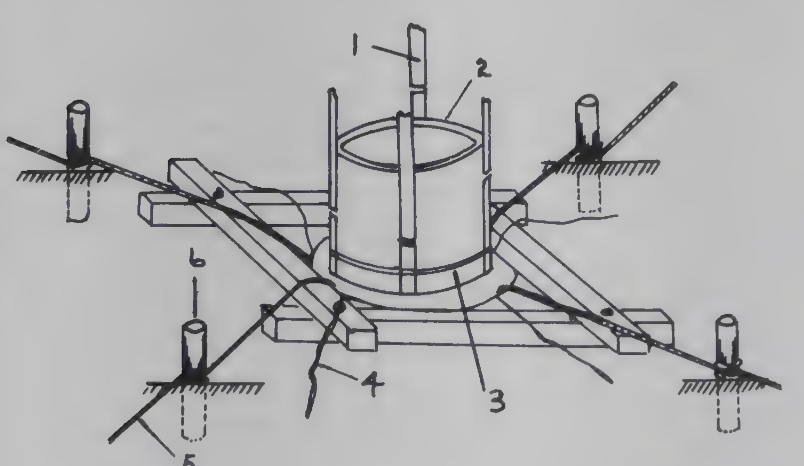


Fig. 57. Pipe-lowering technique (1, thin, flat strips of bamboo; 2, well pipe; 3, galvanized wire tie; 4, secondary cable; 5, main pipe-lowering cable; and 6, wooden pile).

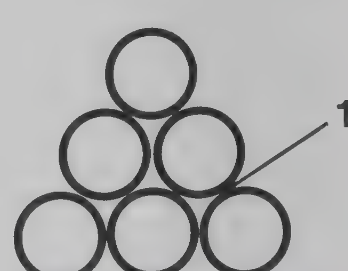


Fig. 58. Arrangement of filter materials (1, space between particles).

tions and at the same depth), an increase of 900 m^3/day.

The piston is made of wood with a groove in the centre, a water outlet in the upper portion, and a water inlet in the lower portion; it is circular in cross section and looks like a date stone (Fig. 59). It is divided in half, and when in use, is fixed on a heavier pulling rod (diameter 50 mm). A rounded piece of iron is welded underneath the "stop ring," weighing down the piston and increasing its speed of descent. A tire or a strip of rubber 8–10 mm smaller than the diameter of the well pipe is nailed in the groove in the middle of the piston. Another piece of rubber is nailed on the top of the water inlet to act as a valve. When the piston ascends, the valve covers the water outlet; when the piston descends, the valve at the water outlet will be pushed aside by the rushing water. The piston should be submerged in water for no fewer than 24 hours prior to being used; this step ensures that the wood does not swell inside the well pipe and become lodged. The ascending speed of the piston should be between 0.5 m/s and 1 m/s. Washing should begin at the upper-most water-containing layer, and the piston should be gradually worked downward. The process should be properly monitored, as it is not advisable to wash the well for extended periods. For fine sand layers, the washing should be carried out until all soil has been removed, the slurry has been cleared, and just a little sand from the water-containing layer gets into the well pipe.

The compressor method is based on pneumatic pressure. The tools are a compressor, water pipe, and air pipe. The two pipes are submerged in the well. The ratio of the depth of air pipe to the total length of the water pipe (the submerged ratio) should be 60–70%. If the submerged ratio is too small, the well will not be completely washed; likewise if the submerged ratio is too high, the compressor may be damaged.

The compressor commonly used has a capacity of 9 m^3/s. The water pipe normally has a diameter of 10.2–12.7 cm, and the air pipe has a diameter of 3.2–3.8 cm. There are two arrangements: concentric and parallel (Fig. 60). How the air pipe is lowered into the well is determined by the characteristics of the compressor, e.g., when a 6 m^3/s compressor is used, the air pipe is lowered into the well up to 60 m. Well washing should be carried out from the upper water-containing layer, and from one layer to the next, finally the well should be washed over its entirety several times.

The extractor method is used when other facilities are not available or when the type of pipe used is not suitable for other methods. The extractor takes up mud and turbid water from inside the well and thereby ensures that the water keeps flowing into the well from the water-containing layer, washing away the stuck soil and clearing the well pipe. This method is very easy to carry out but not very efficient.

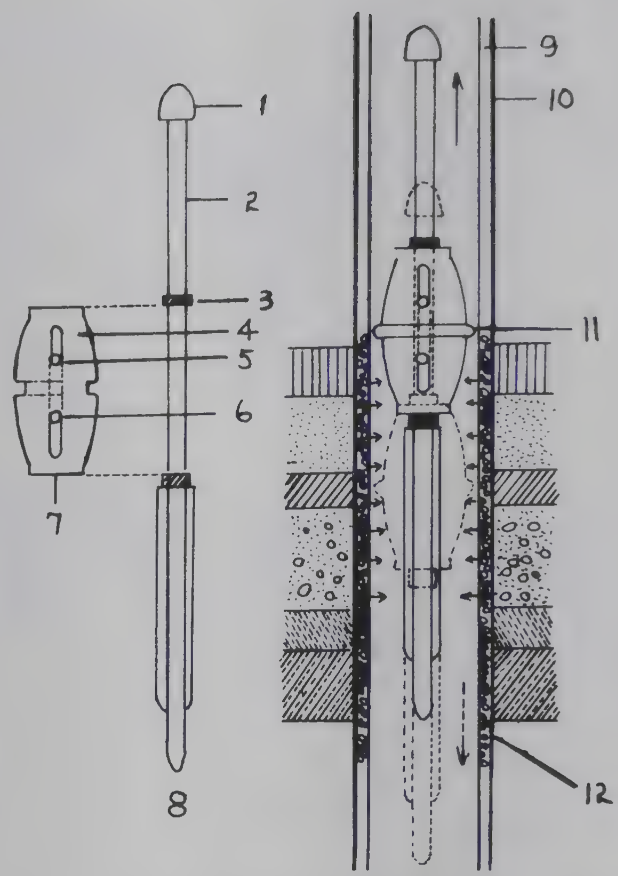


Fig. 59. Piston method of well washing (1, lifting ring; 2, 50-mm round iron bar; 3, stop ring; 4, wooden piston; 5, water outlet; 6, water inlet; 7, wooden piston; 8, pulling rod; 9, well pipe; 10, well wall; 11, tire or rubber strip; and 12, filter material).

The combined compressor and piston method is the best, as it has the advantages of efficiently washing the water-containing layers with the piston and following up with the compressor to clean out any residual dirt. This method is not only fast but also very efficient.

The high-pressure pump method is suitable when there is a large clear-water source adjacent to the well site and when none of the other facilities for well washing are available. A high-pressure pump, however, needs to be complemented by a sand extractor. The method is to pump clear water at high pressure into the well. The pump is made stationary first; then a water-discharge pipe is lowered into the well to clean the walls, the turbid water rising to ground surface via the well pipe. The walls of the well will be cleaned if this procedure is repeated several times. In fact, the clear water can be reused if a

sedimentation pond is excavated next to the clear-water source and the sand is allowed to settle in it. Washing should be done from the top portion of the well down, and the sand extractor used to remove the sand in the bottom of the well.

Water Testing

After washing the well, one must test the water to find out whether the well has been thoroughly washed and also to determine the water discharge as an indicator of the type of pump needed. Water testing is normally carried out with a 90°, V-notch, water-testing box (Fig. 61). The box must be properly placed prior to testing.

Measuring a fluctuating water level is best done with an electric water-level meter (Fig. 62), which uses an electrometer as a measuring device and a dry-cell battery as the source of electricity. One end of a series connection wire is connected to the well pipe or stuck in the ground, and the other end is attached to the measuring head that records the water level. Both the height of the water that flows through the V-notch and the fluctuation are measured. The corresponding water discharge can be found in any standard tables for V-notch wiers. It is better to repeat measurements several times so as to arrive at an average.

Well examination can be done incrementally, item by item, or simultaneously. The former involves examining the important items separately during the construction process and finally putting the well into operation after washing and water testing, whereas the latter is carried out upon completion of construction and under the recommendation of the construction unit. The water is tested and the well is put into operation. Normally, the former method is adopted, because it provides an opportunity for the well users to understand each important item and to monitor the procedures.

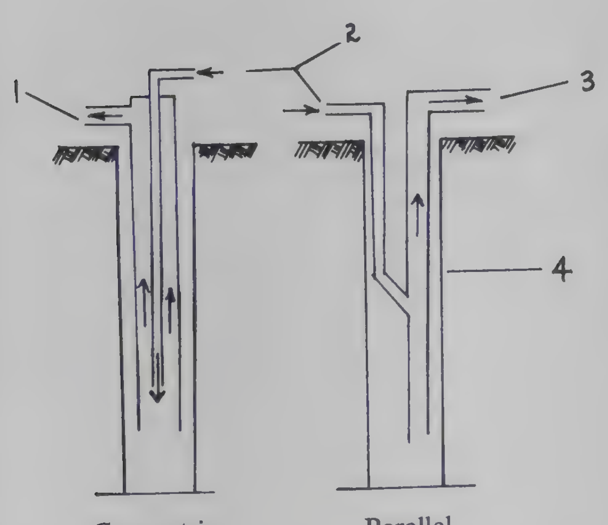


Fig. 60. Air and water pipes in the well (1, water pipe; 2, air pipe; 3, water pipe; and 4, well pipe).

Elements that do not comply with the requirements should be pointed out and rectified. Any problem that raises disagreement should be discussed and resolved. Single examination should only be undertaken if recommended by the construction unit. Whichever the type of examination, it must be carried out in the field by staff from both the construction unit and the users. The construction unit must recommend the items for examination and their quality requirements.

Quality Standards

The steps in examination are to:

- Check all soil samples and sieve analysis results;
- Ensure that the deviation of installed pipe length and well-hole depth is less than 0.2% and the inclination of the well is less than one in a thousand;
- Measure the well-hole diameter and the thickness of filter materials, which should comply with the requirements (normally the thickness of filter materials is 10 cm);
- Make certain that the well pipe is right at the centre of the well hole and that the opening of the pipe is horizontal;
- Determine that the deviation between the filter and the corresponding water-containing layer is less than 0.5 m;
- Establish that the proportions of filter pipe and filter materials and of filter materials and the sand particles in the water-containing layer are correct (Table 12);
- Compare the quantity of filling materials used with that calculated; the difference should not be greater than 5%;
- Check that the seal against undesirable water-containing layers is strong and secure;
- Ensure that all the well pipes have been lowered into the well safely without any cracks or disconnections;
- Measure the sand content with a sand-content measuring cylinder (Fig. 63) after well washing (the amount should be less than 1/10 000 and the water, crystal clear); and
- Ensure that the sodium contents of irrigation water are not greater than 1 g/l Na_2CO_3 (sodium carbonate), 2 g/l NaCl (sodium chloride), and 3 g/l Na_2SO_4 (sodium sulfate) (standards for areas where a water shortage exists can be less stringent).

Upon completion of the well, the construction crew should hand over to the well-operating crew

a final diagram of the geological symbols together with the soil samples, retaining copies. The construction crew should also give the operating crew information about the pump setup and depth of the underground chamber that must be excavated.

Troubleshooting

During construction, failures may occur in the machinery parts or inside the well hole due to either natural factors or human negligence. Failures or obstructions in the machinery can be detected, and, depending on the seriousness of the damage, the machinery will have to be either repaired or removed. Failures inside the well hole can only be detected in the ensuing phenomena. Although there are many failures that cannot be handled properly, and therefore force the well to be abandoned, there are many that can be corrected by the construction workers.

For different types of drills, there are normally salvage tools that are specifically designed to deal with incidents inside the well hole; the main requirement is that the cause of the incident be calmly and correctly analyzed and the location and the depth of the problem measured accurately. Then, a suitable method can be found to deal with the problem. Some common problems during compression drilling and how to deal with them are noted below.

A common incident in percussion drilling is that the drill becomes lodged; if not properly handled, this problem results in serious losses. The main reason the drill sticks inside the hole is that the drilling tool is substandard or needs repair. Other possibilities are that the machinery is being improperly operated by workers trying to speed up drilling; the well hole is not circular; or the diameter of the well hole has become smaller because of a soft soil layer or a rock outcrop inside the well hole. When the upper portion of the drill is stuck, the main causes are a noncircular hole, rock outcrop, reduction of the well-hole diameter, or drill expansion. When dealing with this problem, workers must not force the drilling tool; instead, a secondary windlass should be used to drive the percussion rig slowly. When the bore-bit moves, it should be rotated to an angle that will allow it to be pulled up easily. As an alternative, reverse percussion can be used to break the rock outcrop or any other blockage before the drill is lifted. When the bore-bit is out of the hole, both the bore-bit and the well hole can be repaired. When the lower portion of the drill is stuck, the reason is that the lower portion of the bore-bit has worn more rapidly than the upper portion. When it penetrates to the bottom of the hole, it gets caught in the rock layer. When this happens, a windlass should not be used. Instead, the cable should be pulled tight and shaken vigorously to loosen the drill, or else a jack may be used to raise it. If these methods are unsuccessful, a small amount of dynamite can be used to blast and crack the rock. Once the bore-bit is released, it should be repaired.

A cave-in is a serious occurrence in percussion drilling, the drill always becoming buried. The main reasons for a cave-in are improper use of slurry, lack of slurry, and a running sand layer. A cave-in can actually be foreseen; danger signals are a large piece of earth dropping into the hole, the slurry suddenly rising to the mouth of the well

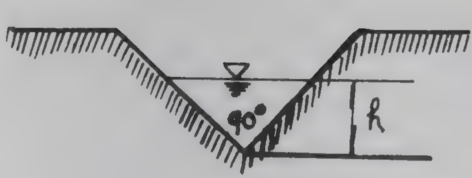


Fig. 61. 90°, V-notch wier.

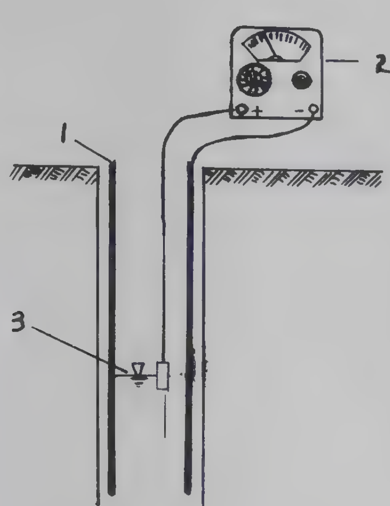


Fig. 62. Water-level measurement (1, well pipe; 2, electrometer; and 3, fluctuating water level).

Fig. 63. Sand-content measuring cylinder.

hole, or the slurry suddenly leaking away. When such phenomena have been detected, the drilling tool should be raised immediately, and an investigation of the situation conducted. If the upper part of the hole caves in, a casing should be installed and completely sealed with clay, or the concentration and viscosity of the slurry should be increased. If the lower part caves in, large amounts of clay should be added so that the specific gravity and the viscosity of the slurry are increased. Also, if the hole starts to leak excessive amounts of slurry, the specific gravity and the viscosity of the slurry should be increased.

Another common problem is the broken bit. When the drill breaks or falls into the hole, a straightness-supporting hook or other tool should be used to stand the bore-bit up; then a catch with a hook or a cable loop should be lowered into the well hole, to pull out the tool for repairs. If the drilling tool has a lifting ring, then a hook can be used to lift it.

Many other incidents can occur inside the well hole, and the methods of handling them vary; if the construction crew takes time to analyze the problem carefully, a suitable salvage tool or procedure can usually be found.

Chapter 8

Manual Well Drilling

The principles of manual and mechanical well drilling are similar, as are the basic requirements of the well, but there are different tools and personnel requirements. The three main manual methods are pot drilling, percussion drilling, and hand digging with caison sinking.

Pot Drilling

A "pot-drill" is a manual rotary drilling machine, suitable for use in clayey soil, sandy soil, sand, and sandy-cobble and sandy-gravel layers where the diameter of the cobble is not greater than 50 mm and the amount of cobble not more than 30%. This tool drills quickly, especially in clayey soil and sandy soil; it is also suitable for flat plains areas where the water-containing layer is shallow.

The diameter of the well opening is determined by the diameter of the "pot-head" on the drill, of which two types are commonly used. A large pot-drill will produce a well with a diameter 1.0–1.1 m and a depth of 30–40 m. A small pot-drill can produce a well with a diameter of 0.55 m and a depth of 60–70 m.

The main components of the "pot-drill" are a boring rod, intermediate rod, pot-head, and bore-bit. The boring rod (Fig. 64) is a steel pipe having a wall thickness of 8–10 mm, a diameter of 70–80 mm, and a length of 4 m. On one end is welded a trapezoid male thread, and on the other, a trapezoid female thread (Fig. 64). Because the boring rod encounters great torsion in the course of drilling, it must be made of strong materials, and the welding must be firm and straight.

The intermediate rod (Fig. 65) is made of no. 45 steel with a diameter of 70–80 mm and a length of 2 m; two surfaces are planed at a fixed distance. The intermediate rod is connected to the boring rod with a screw joint, and a pushing rod (Fig. 66) is placed on top and held so that the force is transferred to the pot-drill portion.

The pot-head consists of a frame, a mud-guard tube, a clutch, the body of the drill, valves, cutters, and upper and lower hole-expanding cutters. The mud-guard tube is a steel pipe with a diameter of 95–105 mm; a clutch is welded to its lower end (Fig. 67). The boring rod is inserted into the mud-guard tube, and the pot-head can move up and down the boring rod. During drilling, the pot-head is seated at the bottom of the well; the boring rod is rotated clockwise, a motion that engages the clutch with the "clutch catch" on the bore-bit, so that the pot-drill will rotate. When the drill is lifted up, the boring rod should be rotated counterclockwise to release the pot-head from the catch of the bore-bit; then the pot-head can be lifted out from the well with a windlass. The frame is made of thin steel plate welded on both sides of the mud-guard tube in symmetric locations. The body of the drill, upper and lower hole-expanding cutters, cutters, and valves are all fixed on the frame. The body of the drill is formed by two pieces of half-circular steel plate that are joined together on the frame by hinges, screws, and nuts. In different soil layers, cutters with various angles are used. Generally the large pot-drill should be 15–20°, and the small pot-drill 25° or 30°; they should be used together with the "cow's horns" cutter. Cutters with a small angle are used to drill the hard and clay layers, and those with a large angle are used to drill the loose layers. A "cow's horns" cutter is used to drill the gravel and cobble layers. The cutters should be made of relatively hard steel, for example, manganese steel no. 65, which is durable. The cutters are fixed on the frame by a screw, so that they can be replaced easily. A valve is installed inside the cutter, where soil is brought in, made of thin steel plate and inlaid with thin India rubber; it prevents the trapped soil from falling out. The valve is attached when a sand layer is being drilled and taken out when a clay layer is being drilled. The upper and lower hole-expanding cutters are fixed on the frame to enlarge the well hole; their functions are to reduce the friction between the body of the pot-drill and the wall of the hole, to reduce the diameter in a loose layer, and to prevent the hole from caving in

Fig. 64. Boring rod.

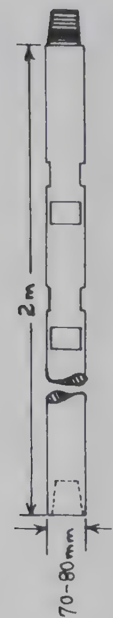


Fig. 65. Intermediate rod.

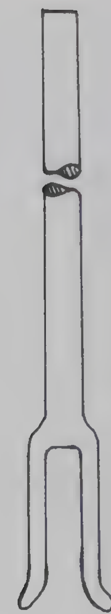


Fig. 66. Pushing rod.

when a temporary vacuum is formed by the lifting of the pot-head.

The bore-bit facilitates the pot-head's soil penetration. There are two types of bore-bits, spiral (Fig. 68) and fish-tail (Fig. 69). The former is used in sandy-loam soil, sand, and cobble-sand layers, and the latter in clayey-soil layers.

Once the pot has filled with soil, it must be lifted and the soil poured out. The claw is one suitable tool for lifting; when lowered into the well along the boring-rod, it grabs the pot-head and lifts it up (Fig. 70). Sometimes, the pot-head is connected to the cable of a windlass (Fig. 71), which is a very convenient tool for lifting and lowering. The windlass is either manually or electrically driven, at low speeds of revolution; it is commonly used for lifting and lowering the pot-head and the boring rods.

In manual operations, scaffolds (Fig. 72 and 73) are needed; a suitable structure for the pot-drill and windlass is made up of four intersectionally bound, 8 m long deal (crytomeria) poles; the vertical distance from the centre is not less than 5 m, and the lower end of each deal pole is buried 0.8 m underground. An awning frame is installed 2.5 m aboveground with a stopping ring on one side, poised above the centre of the well. Protecting planks (two) are placed over the opening of the well, and a second stopping ring is placed in their centre. A pulley is tied at the intersection of the scaffold, and a ground pulley is fixed between two adjacent poles, the structure forming a lifting system with the windlass. The top pulley, ground pulley, stopping ring of the awning frame, stopping ring of the well opening, and the cable of the windlass are along a vertical plane (Fig. 72).

To operate the setup, 12–15 persons are needed, with a leader responsible for the construction work. Four persons are responsible for lifting and lowering the pot-head, removing the soil at the well opening, and preparing to insert the pushing rod into the intermediate rod and rotating it. One person is responsible for closing and opening the stopping ring at the awning frame, two persons supply the slurry, two persons operate the wind-

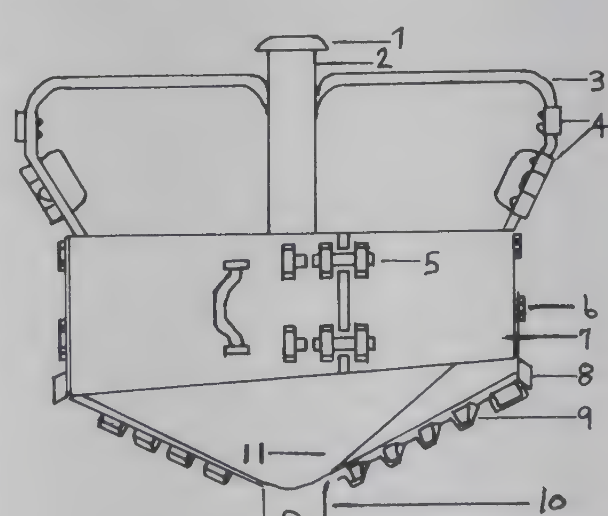


Fig. 67. Large pot-drill (1, flange; 2, mud-guard tube; 3, frame; 4, upper hole-expanding cutters; 5, screw and nut; 6, hinges; 7, the body of the drill; 8, lower hole-expanding cutters; 9, cutters; 10, clutch; and 11, soil inlet).

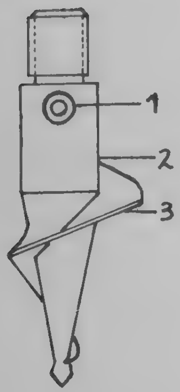


Fig. 68. Spiral bore-bit (1, clutch catch; 2, sharp-cone body; and 3, spiral cutter).

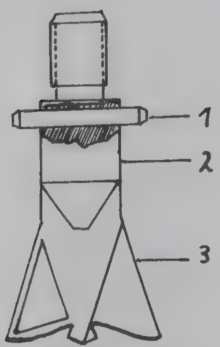


Fig. 69. Fish-tail bore-bit (1, clutch catch; 2, sharp-cone body; and 3, fish-tail cutter).

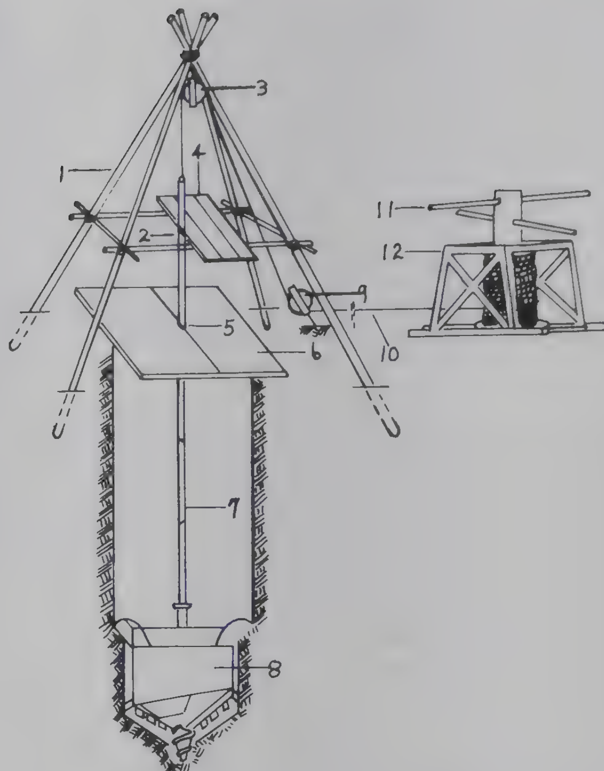


Fig. 72. Scaffold for a pot-drill (1, scaffold; 2, stopping ring at the awning frame; 3, top pulley; 4, awning frame; 5, stopping ring at the opening of the well; 6, door at the opening of the well; 7, boring rod; 8, large pot-drill; 9, ground pulley; 10, steel cable; 11, windlass pushing rod; and 12, manual windlass).

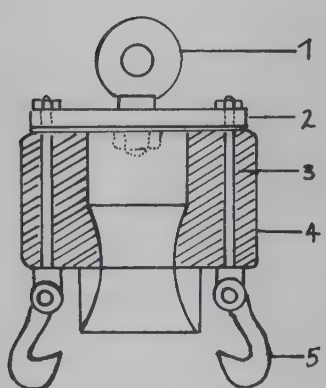
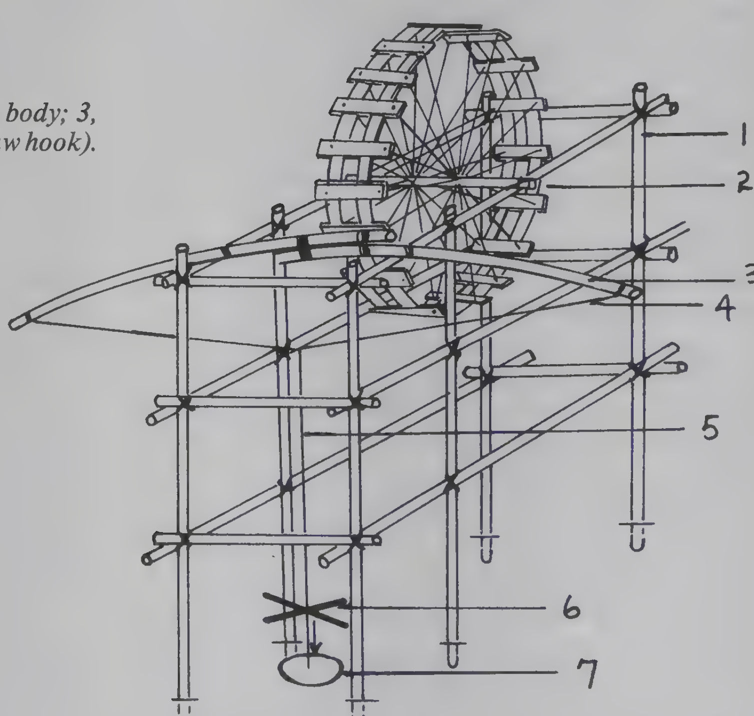


Fig. 70. Claw hook (1, lifting ring; 2, lifting body; 3, lifting rod; 4, supplementary weight; and 5, claw hook).



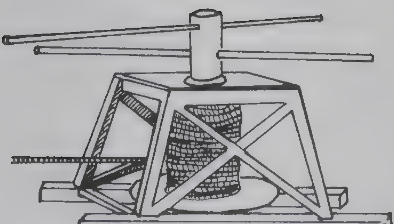


Fig. 71. Manual windlass.

Fig. 73. Scaffold for percussion drilling (1, scaffold; 2, wheel; 3, bow; 4, bow string; 5, lifting rope; 6, press stick; and 7, well opening).

lass, and one person records the information about the soil layers. All take part in pushing the pot except one or two who remain with the windlass; when lifting the pot, all take part in pushing the windlass except one person who remains at the opening of the well.

With this setup, there are several matters requiring special attention:

- Slurry should be kept inside the well at a level not lower than 0.5 m below the well opening;
- The screw joint of the boring rod must be properly protected and kept clean when in use. Faulty boring rods should be rejected, and the number of people rotating the pot should not be more than 8–10; otherwise the risk of breaking the boring rod is high;
- The angles of the pot-drill cutters should be varied according to the type of soil being drilled;
- The pot-head should be lifted and lowered at a uniform speed. It should not be pushed by force, reversed, or shaken; instead, it should be lifted up slightly, changed to another angle and rotated again. If the bottom of the pot becomes slippery and will not advance any deeper, the cutters should be changed to a larger angle;
- Whenever the drilling is stopped, the pot-head should be lifted 2–4 m from the bottom of the well; this measure prevents it from being buried;
- The pot-head should be rotated clockwise so that the boring rod does not fall off;
- When the pot-head is being pushed or rotated in a shallow layer, it should be pushed and filled quickly; in a medium-depth layer it should be pushed and filled slowly; in a deep layer it should be pushed slowly and filled halfway. In other words, the rotating speed and degree of filling must be changed according to the soil layer.

Manual Percussion Drilling

Scaffold drilling is one type of manual percussion drilling and is extensively used in China for deep wells. The structure is simple and easy to make, and the operation can be easily controlled.

The structure consists of a wooden scaffold, a wheel, thin-flat strips of bamboo, bore-bit, bow, bailer, and protective casing at the well opening (Fig. 73).

The wooden scaffold is made of six vertical poles and three layers of horizontal poles. Each vertical pole is 20 cm in diameter, 7 m high, 6 m being aboveground and 1 m being buried.

The wheel comprises the axis, spokes, and stepping planks. The wheel is 4.2 m in diameter; around it thin, flat strips of bamboo are fastened. The axis is made of two steel rods with diameters of 50 mm and lengths of 2.5 m. The wheel has two sets of spokes and two parallel supports for stepping planks. One set of spokes is 14 steel rods 16 mm in diameter; each spoke is slightly longer than the wheel's diameter and a ring is fastened at its centre to fix it to the axis of the wheel. Both ends of the spoke are provided with screws so that the stepping planks can be fixed on top. There are 14 stepping planks, each 1.2 m long, 12 cm wide, and 12 mm thick, their length equal to 7% of the circumference of the wheel; they are joined firmly to the spokes, forming the circumference of the wheel.

The bow should be made of newly felled elm with a diameter not smaller than 20 cm and a length of about 10 m. The bowstring should be steel cable or thick, strong, elastic hemp rope.

Thin, flat strips of bamboo, 50 mm wide, have both ends trimmed to a square joint that allows extension (Fig. 74). They are connected to the bore-bit and facilitate lifting of the drilling tool.

Generally an extractor-type, hollow-valve bore-bit is used. It is made of steel pipe 2.5 m long, with a diameter 200 mm; a strong, bell-mouthed cutter is welded to the bottom of the pipe; a handle joint to the upper part of the pipe. A valve is fixed to the cutter. The welding is with "flying wings" with supplementary heavy reinforcement on the perimeter of the steel pipe (Fig. 75).

The bailer is an iron plate, 5.7 mm thick, rolled and welded to form a 2.5 m long cylinder with a diameter of 250 mm; the bottom of the bailer encases a valve cutter, and the top is welded with a handle joint.

A protective casing made of timber or iron plates, with a diameter of 50–60 cm and a length of 2 m, is used to protect the well opening.

First, the protective casing is placed firmly inside the excavated well opening. The bowstring faces the centre of the well opening; the bore-bit with the thin, flat strips of bamboo is hung by rope on the bowstring. Two intersection sticks are tied on the lifting rope, and then slurry is poured into the well and the bore-bit lowered. Pressing the sticks causes the percussion, and the bore-bit rebounds by the force of the bow. The bore-bit should be rotated during percussion so that the hole being drilled is made circular and vertical. When the slurry becomes concentrated and makes percussion and rebound difficult, the bailer is used to remove the soil. If the thin, flat strips of bamboo are not long enough, several can be connected together by the "square-joint" and made secure with an iron hoop. The wheel is used to bail soil and to lift and lower the bore-bit. Lifting and lowering must be carefully controlled, and the person who steps on the wheel must prevent the

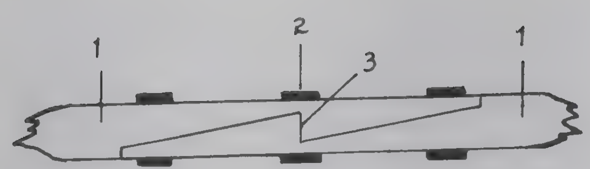


Fig. 74. Joining of thin, flat strips of bamboo (1, slim, flat strips of bamboo; 2, iron hoop; and 3, square joint).

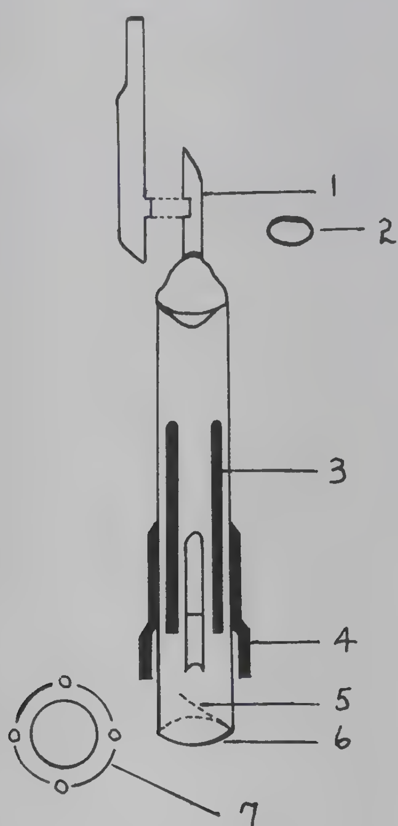


Fig. 75. Bore-bit, (1, joint; 2, hoop ring of the joint; 3, supplementary heavy reinforcement; 4, "flying wings"; 5, valve; 6, bell-mouthed cutter; and 7, view from below).

wheel from running out of control when the well is deep. The section on troubleshooting in chapter 7 is equally applicable to manual percussion drilling.

Matters requiring special attention are that:

- The bowstring needs to be tightened periodically, as its elasticity decreases during use;
- The valve at the bore-bit must constantly be kept flexible; otherwise it will have to be replaced or repaired;
- The cutter and "flying wings" need to be monitored for wear or damage; their dimensions should comply with the standard, and if they become damaged, they should be repaired, welded, or replaced; and
- The wheel and the hoops on the thin and flat strips of bamboo should also be examined regularly; the wheel loosens through use, and the hoops wear out. If these items are not properly maintained, the bore-bit will fall and the thin and flat strips of bamboo will break.

Hand-Dug Well: the Caisson-Sinking Technique

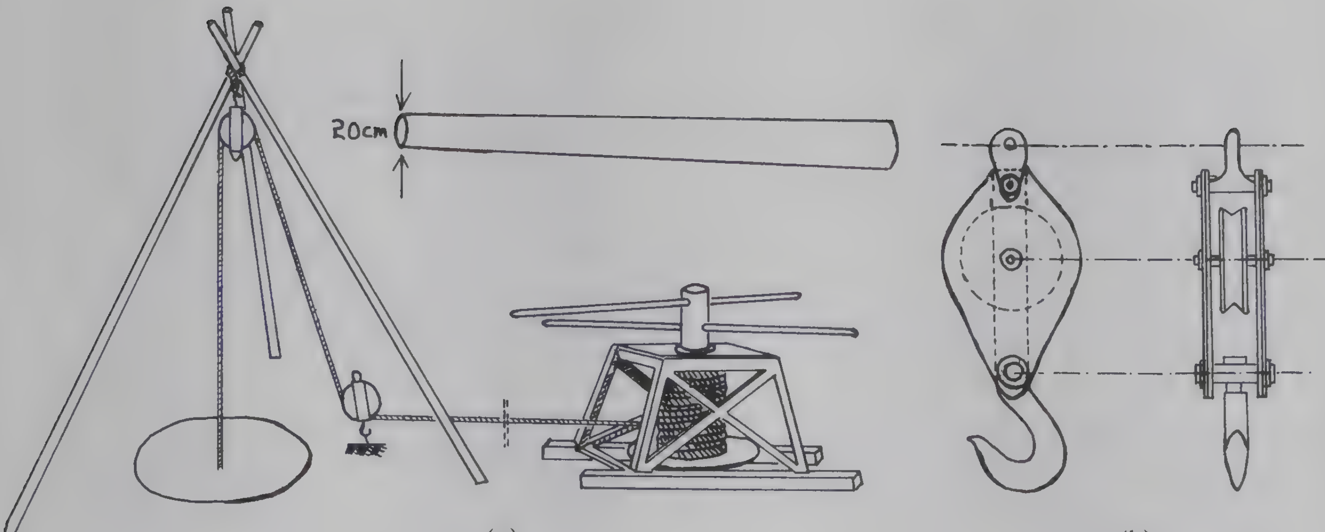
Well sinking is a safe construction method for large-mouthed wells; construction is simple and suitable for a single, water-containing layer close to the surface. The main tools needed are a windlass, pulleys, and a tripod (Fig. 76). The windlass consists of a frame, steel cable reel, electric motor, and handbrake.

There are two pulleys (Fig. 76b), one fixed on the tripod and one fixed near the opening of the well, forming a lifting system with the windlass. The tripod, as the name indicates, is three poles whose diameter is not smaller than 20 cm, tied intersectionally; it stands over the well opening to form a lifting system with the windlass.

The well pipe should be a 125–150 mm thick, double layer, circular steel-reinforced concrete pipe, 1.5–2.0 m in diameter. The filter pipe should be the same type of pipe with small holes as water inlets (Fig. 77).

Bitumen cement is the joint material to be used between pipes, and supporting plates are used to hold them in position (Fig. 78). The joint material is composed of 43% bitumen, 43% cement, and 14% salt. The method is to drill a hole in the side of two pipes 11 cm from the ends to be joined so that the distance between the two holes, when aligned, is 22 cm. Then, after the bitumen mixture has been applied and the pipes placed in position, the supporting plate is bolted to both pipes. Usually the procedure is to attach a supporting plate on each side of the pipes. The supporting plates are 7–8 mm thick, iron, 30 cm long, and 7 cm wide. The holes on the iron plate (Fig. 79) should be slightly larger than the diameter of the screw (2.0–2.5 cm). The screw is 225 mm long or may be made from 250 mm of round steel (Fig. 80); the thread should be 8 cm long. The digging consists of seven persons: an operator, a commander, two to push the windlass, and three to work inside the well. If the progress is fast, the number of persons pushing the windlass and those working inside the well can be increased.

Before well construction begins, a pit deep enough for a length of well pipe should be hand dug at the well opening; then the bottom filter pipe with water inlets should be lowered into the well by chain-block and placed in a horizontal position. The second filter pipe is then lifted by chain-



(a) (b)

Fig. 76. Tools for caisson-sinking technique: (a) tripod and its arrangement in a well field and (b) pulley.

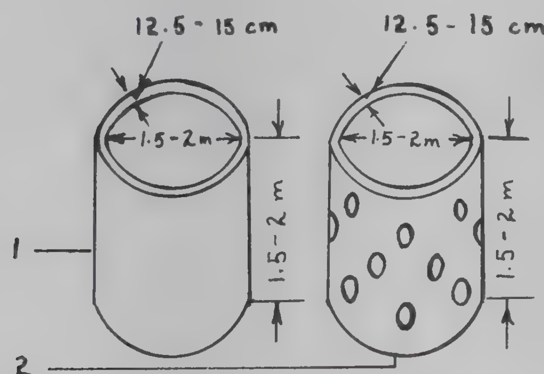


Fig. 77. Well pipes for large-mouthed well (1, solid pipe and 2, filter pipe).

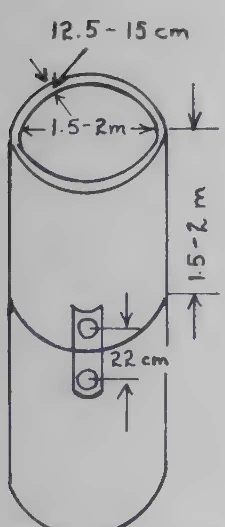


Fig. 78. The joint between the two well pipes.

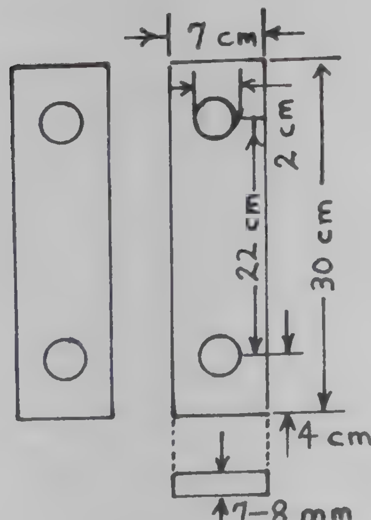


Fig. 79. Supporting plate.

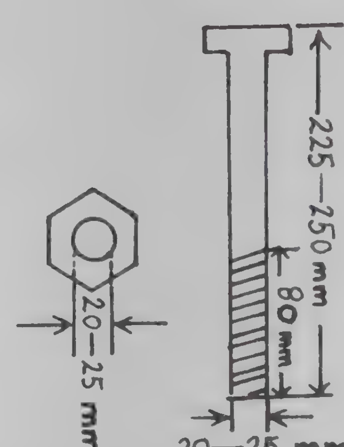


Fig. 80. Screw and nut for pipe joint.

block, a layer of joint materials applied to its end; then lowered onto the first filter pipe, supporting plates being attached appropriately (generally six and eight pairs of supporting plates are used for wells having a diameter of 1.5 m and 2 m, respectively). The screw's thread end should face inside the pipe when the screw is being inserted so that the external pipe wall is smooth and friction during lowering is minimized. Once the pipes are joined, workers should get inside the pipe and begin excavation. It is extremely important that excavation be carried out evenly all around the pipe, so that the pipes stay relatively level as they sink and strain on the joints is minimized. When groundwater is encountered, it should be pumped out before excavation is continued; all the soil layers should be recorded in a drilling log as the work progresses (see chapter 7).

Advantages

Because the well-sinking method uses precast well pipes, it is not necessary to support the wall of the well. Cave-in does not occur during construction, and the people working inside are safe. The method is labour-saving compared with others using brickwork. Penetration through running sand layers is relatively simple, and in an area where the water is deep underground, the workers can dig as deep as 60 m.

This method should be employed in a dry season when the underground water is at a minimum, as this makes work easier and guarantees the water discharge upon completion.

When the well is completed, a pump stage should be constructed 1.5 m higher than the highest water level and the pumping equipment installed on it.

Chapter 9

Well Repairs and Damage Prevention

Due to their poor quality and improper maintenance and operation, some well pipes become disconnected; damage is caused by sand, and siltation occurs. The discharge from the wells becomes markedly reduced, and some even have to be abandoned. To regain water output and further agricultural production, workers not only must build new wells but must repair and maintain old damaged wells. A standard procedure has been established for checking, repairing, and preventing well damage. In China, more than 100 damaged wells have been renovated, all regaining their original capacity.

The methods of repair and prevention are economic and simple, and they produce good results. They have been popularized widely in China and are fully accepted by the people.

Well Inspection

According to field surveys, the causes of damage to open-mouthed, concrete wells are poor design and construction, improper maintenance and operation, and improper diagnosis and handling of problems (see chapter 7). Some of the common manifestations of the three causes are:

- An air pocket forms next to the well wall and causes the pipe to collapse; the construction fault is that (1) the diameter of the hole is much larger than that of the well pipe, (2) the thickness of the gravel filling layer is less than 10 cm, or (3) the gravel filler has been added too quickly and, hence, has created obstruction; when pumping is under way, sand enters the well and the external filler moves to produce the air pocket;
- Part of the pipe sinks and becomes disconnected; this indicates that (1) the final drilling did not reach an impervious layer of clay, (2) the well hole was not cleared before the well pipes were lowered, or (3) the pipe does not reach the bottom of the hole;
- The joints open or crack when pumping begins; possible causes are that (1) the well hole is not straight, (2) the well pipes are not round, (3) the joint is not properly reinforced, or (4) the quality of the clay rings is poor; and
- The water discharge is minimal, or siltation is apparent in the water; these problems probably reflect (1) an incorrect proportion between the particle sizes of the filter pipe aggregates or the gravel filling layer and the particle sizes of the water layer, (2) irregular filter materials such as kiln dregs or brick being used as filler, or (3) the well not being covered or protected by a pump house or well platform so that stones, bricks, or mud have been thrown into the well or have been washed into it by heavy rains.

The most common mishandling of a problem is the use of some object, such as a cone, to remove sediment or to knock down obstructions in the well. This approach to the problem of blockage or siltation often results in broken pipes.

Abrupt changes, for example, a discharge of brackish water, an extensive blowout of sand, or a decrease in water quantity, indicate that the well pipe has broken; the pump must be switched off immediately before the well wall collapses. In such circumstances, the pumping facilities should be taken from the well and the damaged well pipe examined carefully. The steps are to insert a measuring rope and determine the height of siltation inside the well, an approximation of the location of damage. When the pipe breaks, the gravel filler becomes damaged because during pumping water feeds continuously from the water-containing sand layer into the well and brings with it sand particles. The particles settle until they reach the height of the breakage.

A more accurate and immediate checking method is to use a soil-receiving container (Fig. 81). The soil containers are firmly joined in series at 1 m intervals by a measuring rope. The containers are made of no. 8 galvanized wire that has been bent into a circle and gauze that has been sewn securely to the wire ring in a cone shape. The diameter of the container is 2–3 cm smaller than the internal diameter of the well pipe so that it can

be easily lowered into the well. A heavy weight is hung at the bottom of the measuring rope, a small piece of brick is placed inside each soil-receiving container so that the measuring rope remains parallel to the well pipe and the soil receivers are kept upright and stable. First, the soil-receiving containers are lowered into the well, then a rubber suction pipe is installed, and the pump is switched on for 3–5 minutes, the sand particles in the water-containing layer immediately flowing into the well. Then, the rubber pipe and soil-receiving containers are withdrawn and their contents examined. Sediment in a soil-receiving container means there is a break somewhere above that container.

If the level of silt has already reached the break, this method cannot be used. The well must be cleaned or washed before the examination. A pressure hose is used to wash out the sediment. A 3-inch (7.5-cm) diameter rubber tubing connected to a 20-mm diameter steel pressure hose (Fig. 82) is lowered to about 300 mm above the sediment. Then, the water is pumped out. The pressure will scatter and wash out the sediment as the water flows out of the well. As the depth of sediment is reduced, the pressure should also be gradually reduced, especially near the area where the break is thought to have occurred. After the hose has been lifted up, water has to be reintroduced into the well to keep up the pressure until the examination with soil-receiving containers and the repair of the well pipe have been completed.

If damage in the well pipe is only a crack or a few small holes, then repair work can be carried out at once. However, if the well pipes have become disconnected then a pipe-knocking instrument has to be used to bring the pipes into correct position before any repair work can be done. To indicate the nature of damage, a guiding instrument (Fig. 83) is used. This instrument is a 4-m long rod with lantern-shaped bamboo bows fixed to both ends; the diameter of the lantern shape must be 3–4 cm smaller than the internal diameter of the well for easy insertion. During examination, the guiding instrument is lowered gradually into the damaged portion. If it passes through without obstruction, the implication is that the side of the well pipe is broken; if its pathway is obstructed, the well pipes are probably disconnected. The pipe-knocking instrument (Fig. 84) can be used to bring the pipes into line. The pipe-knocking instrument is similar to the guiding instrument except that the two bamboo-bow circles in the latter are replaced by an elliptical piece of wood, tightened by a screw. Its function is to knock, repeatedly along the length of the well until the pipes are brought into their correct position.

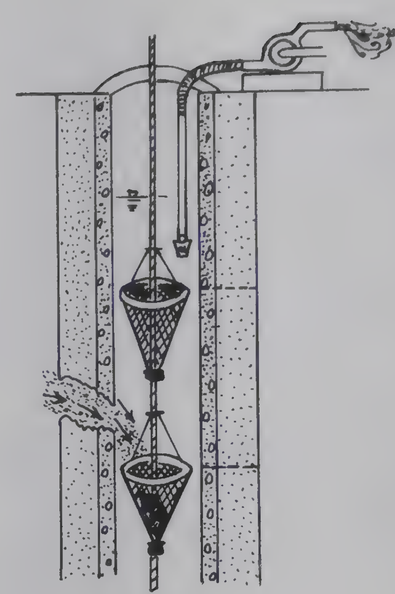


Fig. 81. Soil-receiving container: a tool to locate damage in a well pipe.

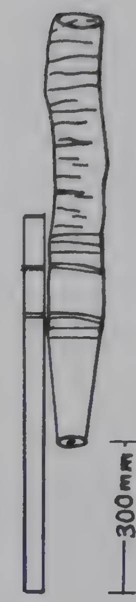


Fig. 82. Pressure hose.

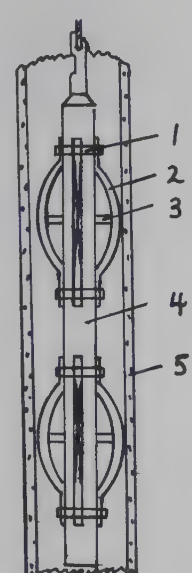


Fig. 83. A guiding instrument (1, galvanized wire fastening; 2, bamboo bow; 3, supporting pole; 4, core; and 5, well pipe).

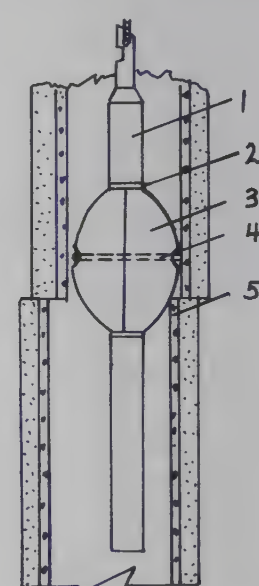


Fig. 84. Pipe-knocking instrument (1, core; 2, galvanized-wire fastening; 3, knocking pole; 4, screw; and 5, well pipe).

Well Repair

Repairing a damaged well consists of placing a repair pipe in the well; this procedure seals the broken hole, stops the sand from coming in, and restores normal water supply. The structure, shape, and material of the repair pipe depend on the structure and type of the well as well as the location and type of damage. The three types of materials used are plastic, sheet metal, and bamboo-

strip matting (coir). The three types of repair pipe are fixed-diameter, variable-diameter, and bell-mouthed. Its structure can be either fixed or movable.

There are two main parts to the repair pipe, the seal and the support. The seal is provided by two bamboo-mat bowls, one attached to each end of the repair pipe; the support is a mechanism in the middle of the repair pipe, a holder, that supports and stabilizes the pipe.

The bamboo-mat bowl (coir bowl or head) is designed according to the shape of the well; it can be either fixed or movable (expansive or contractive). A bowl with a fixed diameter is used in damaged wells that have the same diameter throughout, whereas a movable bowl is used for repairing damaged wells that have a larger diameter at the upper end. The fixed-type bowl is made from three or four layers of bamboo-strip matting. The width of the bowl is 20 cm, which consists of one expansive bamboo ring wrapped with a layer of plastic cloth that protects the bamboo sheet and increases its smoothness. The construction of the movable bowl is similar, but the upper bowl is fixed and the bottom bowl expands and contracts. The bottom bowl is made of three layers of bamboo-strip matting sewn into one piece with string, the upper end tied firmly with galvanized wire and the lower end pressed hard with iron sheet; the inner ring is supported by two bamboo rings. The iron sheet ring is 10 cm wide, and its diameter is slightly bigger than the outer diameter of the repair pipe so that it can move vertically. Two poles are fixed symmetrically to the iron ring. A rope is fastened to the upper ends of the two poles. At the bottom of the iron ring, a supporting plate is attached with two galvanized wires. When the poles are lifted, the iron ring moves upward, the supporting plate forces out the holders, and the diameter of the bowl enlarges and seals up the opening between the repair pipe and the well pipe (Fig. 85). The support or holder is a 2–3-mm thick black iron sheet forming a 12-cm long teeth-shaped iron claw. According to the length and weight of the repair pipe, the claw is either fan-shaped or bat-shaped, nailed directly onto the repair pipe, three teeth facing up and two teeth facing down, in order to increase the stability. This shape is suitable for short (e.g., 2–2.5 m), light sheet-iron repair pipes. Another type of holder is an iron claw nailed to both ends of a bamboo bow. This holder uses four pieces of 80-cm long by 4-cm wide bamboo sheet that are formed into bows. The rough surfaces of the bamboo sheet are smoothed; the sheet is soaked for an hour and heat is applied at the centre so that a bow can be formed. The centre of each bow is tied with no. 10 galvanized wire firmly onto the repair pipe. This holder is suitable for 2.5–3 m repair pipes. At the base of the expansive and contractive part of the holder, small springs made of no. 12 steel wire are fixed all around to squeeze the repair pipe to the inner wall of the well.

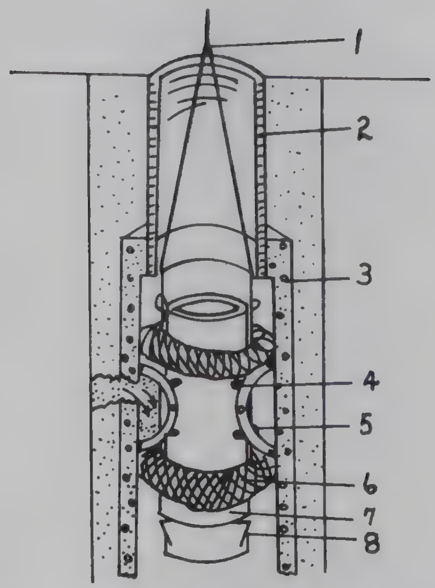


Fig. 85. Repairing a narrow well (1, rope; 2, iron pipe; 3, cement pipe; 4, iron-claw fixer; 5, pole; 6, expanding–contracting bowl; 7, iron ring; and 8, supporting plate).

Unlike standard plastic repair pipes, the sheet iron and bamboo matting pipes are made by hand. The sheet-iron pipe is steel rolled into the form of the repair pipe. Based on the type of well and the position of damage, the repair pipe is a uniform diameter, a variable diameter, or bell-shaped (used to repair the holes in concentric pipes, variable pipes, and wide-mouthed pipes respectively) (Fig. 86).

Bamboo/palm coir repair pipe is made from several old discarded cart hub rings, which provide the internal support, and 4 cm-wide bamboo pieces that are nailed 1 cm apart onto and around the hub ring. The number of rings depends on the length of repair pipe; their diameter depends on the internal diameter of the damaged well. The repair pipe is wrapped with a plastic cloth, five layers of bamboo, and another layer of plastic cloth, all of which is firmly tied with no. 20 galvanized wire. This type of pipe is cheap, and the materials are easily obtainable; it is suitable for repairing large-diameter brick and cement pipes.

After clearing the sediment in the well, examining the position and characteristics of damage, selecting the structure and shape of repair pipe, workers can begin installing the repair pipe and

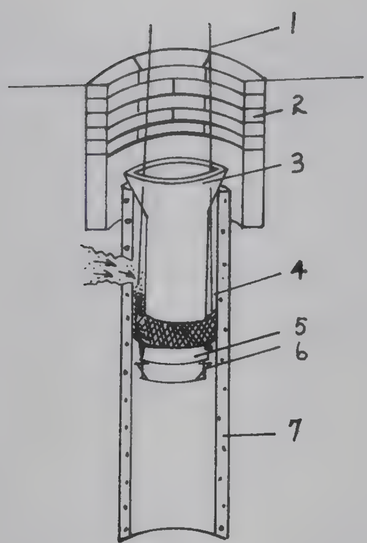


Fig. 86. Repairing a wide-mouthed well (1, rope; 2, brick pipe; 3, bell-mouthed sheet-iron repair pipe; 4, pole; 5, iron ring; 6, supporting plate; and 7, cement pipe).

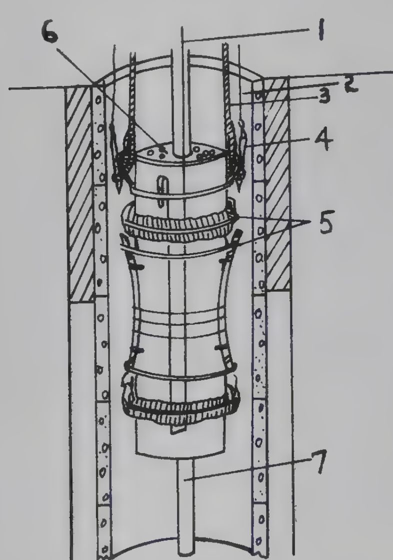


Fig. 87. Lifting and lowering the repair pipe (1, rope-cutting [no. 10] galvanized wire; 2, wire; 3, insert wire; 4, insert; 5, rope; 6, wooden cover; and 7, boring rod).

doing the renovation. The method and tools for the installation (Fig. 87) are:

- Pipe-lowering tool, which is a boring rod longer than 4 m with steel wire attached to the top and T-shaped wooden covers attached to the upper half to press the pipe down. Holes in the wooden covers reduce the buoyancy when the water is being replaced. More than 30 cm of pipe must be pressed down.
- Pipe-releasing insert, which resembles a cone, 1 cm wide × 10 cm. A rope is connected to the pipe by means of this insert. When the repair pipe has been lowered to the damaged area, the insert is pulled out and the rope released.
- Rope-cutting (no. 10) galvanized wire, which is used to lower the pipe. Before installing the repair pipe, workers must ensure that the rope tying the bamboo-arc ring to the bamboo-matting bowl and the iron claw holder is tight so that the external diameter of the repair pipe is minimized and the pipe can be easily lowered into the well.

After the repair pipe has been placed in position, all the ropes have to be cut so that the repair components expand and fulfill their purpose. The ropes are cut with a piece of no. 10 galvanized wire, longer than the depth of the installation, with one of its ends connected to the insert and tied firmly at the opening of the repair pipe and the other end passing through all the ropes that have to be cut and extending out of the well. Pulling the galvanized wire cuts the ropes; then the bamboo-arc ring in the bamboo-matting bowl and the iron claw of the holder will expand so that the repair pipe is squeezed against the inner wall of the damaged pipe (Fig. 88). After the repair pipe has been installed, a pressure hose is used to wash out all the sediment. Because of improper repairs or discovery of new holes below a repair, sometimes a repair pipe must be lifted and further repairs done. The tools and technique for lifting the repair pipe are comparatively simple: a crimped hook is used for lifting; it is made of a boring rod (32 mm diameter) with a trapezoid-shaped knife fixed at the bottom (Fig. 89). Holes are drilled at both ends of the knife and steel wire attached; the knife is bolted at its centre to the boring rod. The apparatus is lowered into the well, one of the steel wires being pulled so that the knife is nearly vertical and is able to pass through the repaired area completely; then the other steel wire is pulled so that the knife is horizontal and can act as a lift for the repair pipe.

Well-Construction Technique

The quality of a well depends on its construction, maintenance, and use, and there are several key elements that should be emphasized. These include:

- The diameter of the excavated hole, which must be based on the thickness of the well pipe and the water-filtering layer; generally, it must be 20 cm greater than the outer diameter of the well pipe so that the water-filtering layer is the correct thickness.
- The soil layer at the bottom of the hole, which must be a hard, solid, impervious layer to

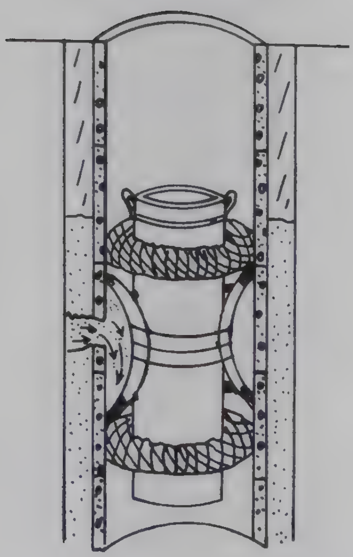


Fig. 88. Installed repair pipe.

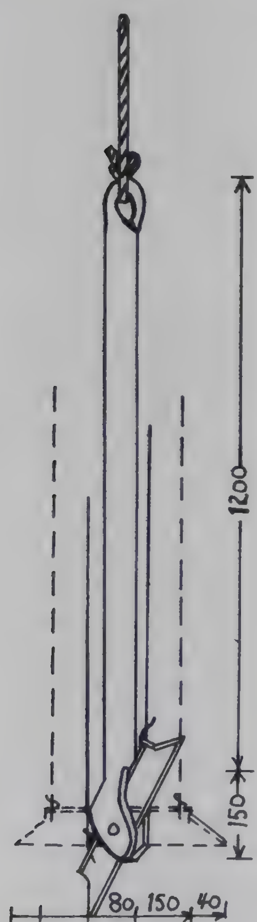


Fig. 89. Crimped hook for lifting repair pipe (unit = mm).

prevent the well pipes from settling, disconnecting, or sliding out of line.

- The particle size of the aggregate (gravel) for a multiporous, concrete, filter pipe, which should be 16–20 times the average particle size of the sand in the water-containing layer, whereas the average particle size of the gravel-filter layer should be 8–10 times as great.
- The well shape and diameter of the well pipe opening, which depends on the type and standard of water-pump facilities; in some cases, the upper portion of the well has a larger diameter than does the lower portion, and they are joined by an adapter. In such cases, a deep-well pump with a large capacity can be installed.
- The quality of the multiporous filter pipe, which must be strong enough to withstand pressure and at the same time porous enough to allow water to pass through; the mouth of the pipe must be horizontal and circular; good strong adhesive bitumen, sand, slurry, and clay improve the strength of the well pipe and thus prevent disconnection, opening, sliding out, and breakage.
- The standards and performance of the filter layer, which must be appropriate to the water-containing layer; the gravel filling must be 2–5 m higher than the filter pipe and must be added consistently, slowly, and continuously.
- The timing of well washing, which should be immediately after construction has been completed; while the well is being washed, the pump must be operated at a higher rate than that used for normal pumping, and washing must continue until the turbid water turns clear. Whenever sediment occurs inside a well, the washing should be repeated.
- The contents of the pump house, which must include all the facilities necessary for maintaining the pump.
- The special washing of the multiporous filter pipe, which is accomplished with a wire brush (Fig. 90) and a water-jet (Fig. 91); this is not

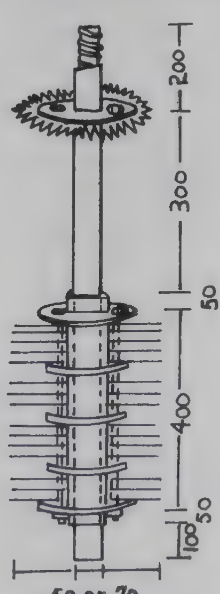


Fig. 90. Steel-wire brush (unit = mm).

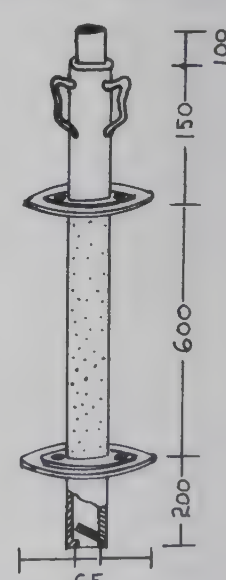


Fig. 91. water-jet (unit = mm).

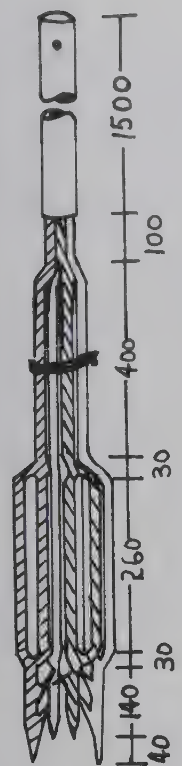


Fig. 92. Brick-salvaging equipment (unit = mm).

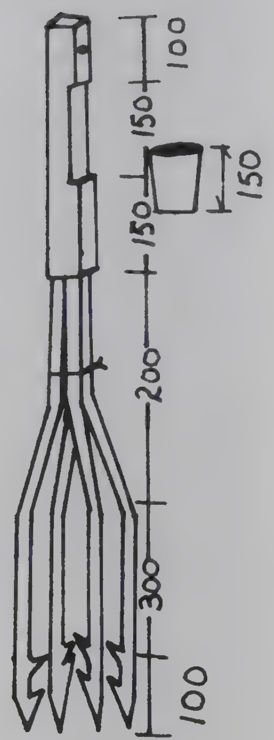


Fig. 93. Fork-and-hook instrument (unit = mm).

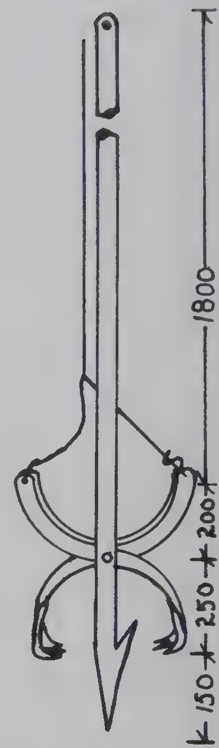


Fig. 94. Piercing rod (unit = mm).

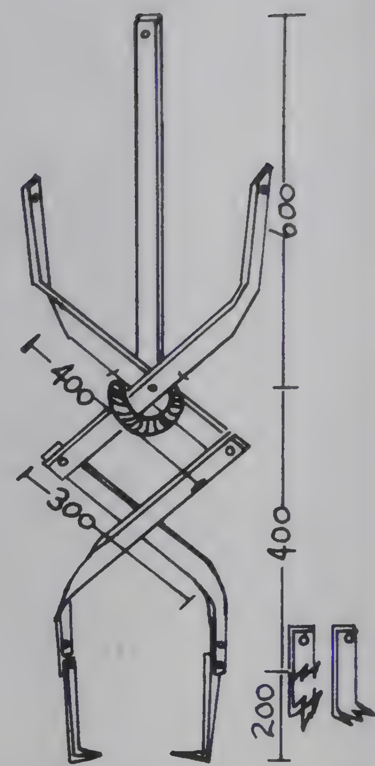


Fig. 95. Multipurpose hook (unit = mm).

always required, but when washing is delayed or is improperly done, the clay wall of the well hole hardens, and particles in the water-containing layer sift into the porous spaces of filter pipe, leading to a reduction or cessation of water output. The wire brush used is made of flanged pipe onto which steel wire has been fixed. At the upper part of the brush, the flanged pipe has a rubber gasket. A boring rod is attached to the brush. The apparatus moves up and down, brushing the inner wall of the well. The water-jet is used after the brush; it is attached to a 3-inch (7.5-cm) rubber tube and, when operating, washes the surface of the filter pipe, forcing water through the pores and washing out all settled particles.

Salvaging Tools

Frequently in the use of a well, bricks fall into the well and sink to the bottom or get stuck between the pipe and the well wall. They can be removed with specially designed brick-salvaging equipment, fork-and-hook instrument, and piercing rod (Fig. 92–94).

Brick-salvaging equipment consists of a boring rod welded to four steel bars. The central portions of the bars are bent to form a drum that can hold the brick. At the ends there are hooks to prevent the brick from falling out again. The instrument is lowered into the well with a pulley fixed at the well opening, and the steel wire is gradually moved into a vertical position so that the brick can be scooped into the drum and lifted. The impact of the brick-salvaging equipment sometimes causes a few bricks to be pushed into the corners at the base of the inner well wall, reducing the efficiency of salvage. Then the piercing rod and fork-and-hook instrument provide help. When bricks land at the joint between big and small well pipes, piercing equipment should be used because other instruments may damage the edge of the pipes. The size of the brick-salvaging equipment and fork-and-hook instrument is dependent upon the internal diameter of the well pipe. If the bricks are covered by sediment, then they have to be removed after well washing.

The multipurpose hook (Fig. 95) is made of four 40 mm × 12 mm flat iron bars joined by a movable shaft. The multipurpose hook is opened by impact and held closed by a spring. Several types of hooks can be attached to it as required. When the upper steel wire is attached to a rubber suction hose, the multipurpose hook can be used to withdraw most odds and ends that drop into the well.

Chapter 10

Experiences in Repairing Wells

In well construction, maintenance, and use, as in many endeavours, there is a large gap between theory and practice, in which any number of problems may occur. A knowledge of some specific problems that have beset others and how they were handled can provide insight into problem-solving and can sometimes save needless work. In Henshui district of Hebei province there has been considerable experience in well repair; some of the details are especially noteworthy.

For instance, after deep-well pumps had been installed on some of the 8-inch (20-cm) diameter, concrete-pipe wells, it was found that the vibration and friction of the suction and discharge pipe damaged the well pipe. As a result, underground saltwater or sand particles were able to enter the well. The first thing to do was to determine the location of the damaged pipe.

The single-electrode method was used. The way it works is that an electric current is passed along the sides of the well pipe and measured. The value measured at a hole is higher than at any other place along the pipe. This method is especially good at detecting a disconnected pipe or a large hole. In the well situated 100 m northwest of Xia village, this method showed that the well was damaged at a depth of 13–13.2 m (Fig. 96). This is the depth of the deep-well pump head — the damage being caused by the vibration of the head during pumping.

The components used in the single-electrode method include a single electrode, a potentiometer (model UJ-18), a battery, a galvanometer, and a ground electrode. The single electrode is made of wood; it is hollow and three groups of galvanized wires are wound around it: the centre group for creating a barrier. A triple cable is inserted through the centre of the electrode and each of the three lines is connected with one group of the galvanized wires (Fig. 97). The battery supplies the electric current; the potentiometer measures the current on the electrode; and the galvanometer registers changes due to differences in the conductor (well wall). The ground electrode completes the circuit (Fig. 98), offering least resistance if it is a metal plate connected to a wire and placed inside a waterfilled hole adjacent to the well.

The method is to lower the single electrode into the well pipe, record readings from the potentiometer of the electric current at different depths from the bottom to the top, plot, on a graph, the depth as the ordinate and the electric current as the abscissa to form a curve showing the variations in electric current. Once the circuit is on, the three groups of electrodes on the single electrode have the same electric potential; the upper and lower barrier electrodes prevent the electric current from flowing either up or down from the centre electrode, so that it can only discharge horizontally. During the measurement, the electric current passing through the broken part of the concrete pipe is greater, its measured value is

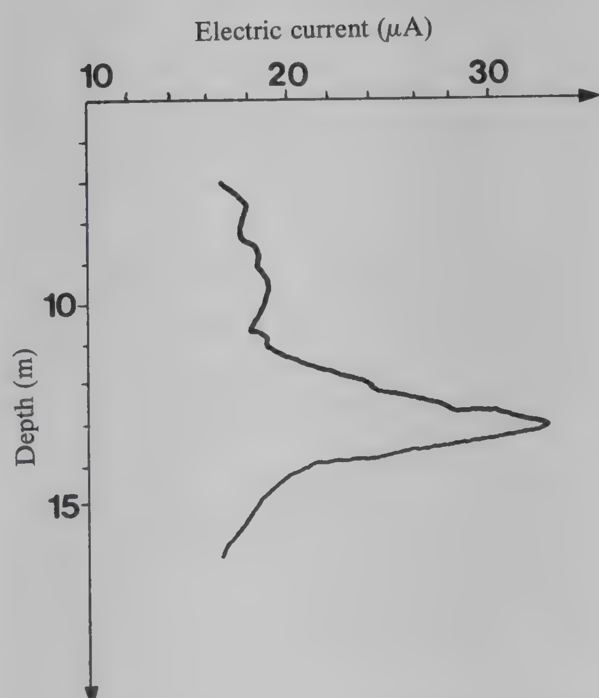


Fig. 96. Curve showing the damaged well pipe at Xia village.

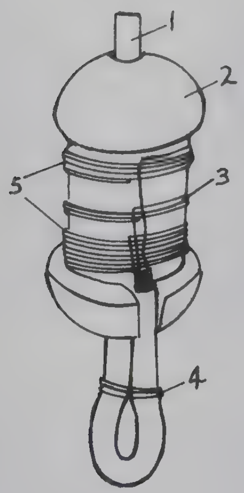


Fig. 97. Single electrode (1, electric cable; 2, wooden electrode; 3, measuring electrode; 4, galvanized wire; and 5, barrier electrodes).

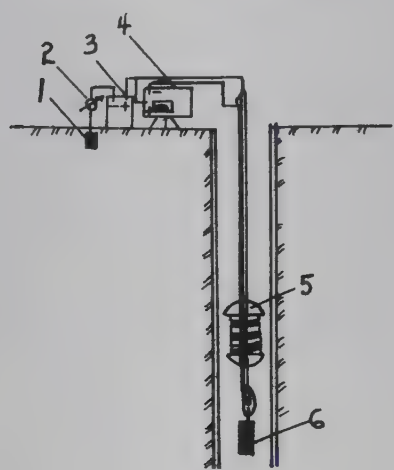


Fig. 98. Connections for single-electrode method (1, ground electrode; 2, galvanometer; 3, battery; 4, potentiometer [model UJ-18]; 5, single electrode; and 6, weight).

higher, and the damage in the pipe can be located from the curve.

Matters requiring special attention are the electric potential of the electrical supply, which should be kept constant during the measurement; the ground electrode, which should not be moved during the measurement; and the single electrode, which should be rubbed clean after use.

Another method of locating damage in a well pipe is the electrical measurement method, which was invented by an investigation group of the Chi district. The basic principles are similar to those of the single-electrode method — to create an electric field and then to use a potentiometer (model UJ-18) to detect the changes in resistance in the concrete pipe. In a concrete-pipe well, the resistance of the pipe is greater than that of the ground layer so that the electric current along an undamaged pipe is consistent but abnormal where there is damage.

The main facilities needed in this method are a potentiometer (model UJ-18) to measure the electric potential difference and the electric current inside a well pipe; a battery (36–72 volt) to supply electricity; and a stepping electrode system (four electrodes, A, B, M, N). Electrodes A, M, and N are lowered into the well. The electric field is formed by the electrical supply electrode A and the ground surface electrical supply electrode B; this is used to measure the electric potential difference between electrodes M and N and the strength of the electric current from the supply (Fig. 99).The method of operation is to connect the circuit (Fig. 100), lower the electric cable to the boundary between salt- and freshwater, raise the cable and carry out measurements at half-metre intervals, record the electric potential difference and the electric current value, and calculate the resistance (K [V/I], where K = coefficient of insulation or 2.26, V = electric potential difference, and I = electric current). The last step is to plot, on a graph, the depth as the ordinate and the resistance as the abscissa. A substantial change in resistance marks the location of the damage.

Some other methods of locating damage have been invented by the well-repairing groups in the Chi district and the Chauchiang district and have proved successful. When turbid water appears in a normally functioning well, workers in these areas first visually examine the pipe above the water level, using a flashlight (most efficient at night). If no damage is detected, it is assumed that the damaged area is below the water surface. The position of such damage is judged from the pipe of the deep-well pump, i.e., the highest part of the pipe that carries turbidity is the location of the damage. To determine this, workers use a simple sieve technique; when a fine-mesh sieve the diameter of the well is placed in the well and raised slowly, it will filter out the turbidity as soon as it is raised above the damaged area. The sieve is simple to construct. In the Chinese districts where it is used, the sieve is a flange, having a diameter smaller than the internal diameter of the well pipe, that has been welded onto a drilling rod and surrounded by a palm-matting net (Fig. 101) whose outer diameter is the same as the internal diameter of the well pipe. It is lowered into the well by galvanized wire; then a submersible pump is lowered to just above it. The pump and sieve are raised simultaneously, the submersible pump being operated while being lifted. When the sieve is above the damaged area, the water pumped out

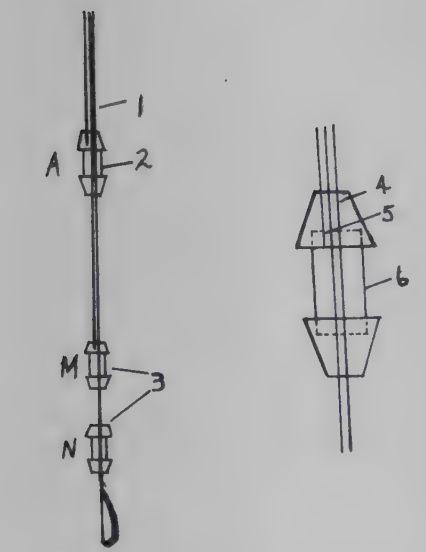


Fig. 99. Electrode system for the electrical measurement method (1, triple cable; 2, electrical supply electrode (A); 3, measurement electrodes (M and N); 4, high-voltage insulating rubber cloth; 5, cable connecting the lead electrode; and 6, lead cell).

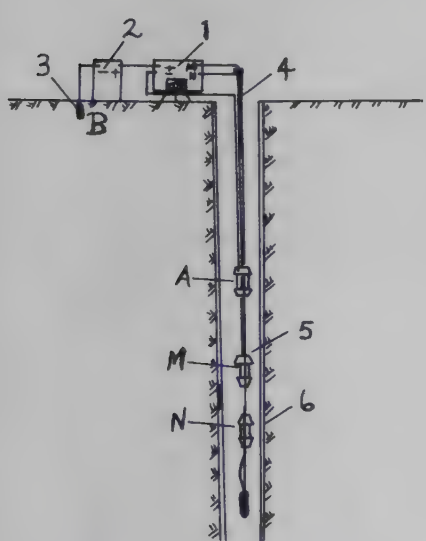


Fig. 100. Circuit connections for detection of damaged areas in a well pipe (1, model UJ-18, potentiometer; 2, battery; 3, ground electrode; 4, cable; 5, electrode system; and 6, well pipe).

Fig. 101. Sieve made of palm matting.

will suddenly become clear. Repeating this process several times reveals the exact position of the damage.

Realigning Pipes and Replacing Damaged Ones

In the development of irrigation for agriculture, many areas have found centrifugal pumps inadequate and have had to replace them with deep-well submersible pumps. The deep-well pumps used in China are often almost as large as the internal diameter of the well pipe; if the well pipe is slightly bent, the deep-well pump cannot be lowered. The bent portions must be straightened or exchanged for pipe of a larger diameter. Also, sometimes, the well pipes are damaged during the installation of the deep-well pump and need to be repaired.

To straighten bent pipes, the people of Chi district have invented a method using a hollow cone to drill holes around the well. The procedures are to excavate a working pit around the well pipe, with a diameter of 2.5 m and a depth of 3–4 m (Fig. 102), build a rectangular wooden scaffold above the pit, and tie a wooden bow (made of elm or date wood, 4–5 m long) on the scaffold, with a bowstring made of hemp rope or no. 8 galvanized wire (Fig. 103). The next step is to install, at the bottom of the working pit, a 1-m high protective casing around the well pipe (20-cm pipe needs a 50–60 cm-diameter casing, and 30-cm pipe needs a 80 cm-diameter casing) (Fig. 102). Once these preparations have been made, the final steps are to drill holes with a hollow cone (Fig. 104) around the well pipe until the lowest part of the bent pipe is reached (Fig. 105), then to drill around the pipe so that the joints between pipes are movable, and, finally, to lower, while rotating, different pipe-straightening devices, such as a big bamboo rod or a deep-well pump, into the bent pipe (Fig. 106). The people of Chi district have found that the length of the drill can easily be extended by the addition of sections of pipe or sticks of wood. Sticky clay is used to seal around the well pipe, and the pipe-straightening device is withdrawn 3–5 days later.

Matters requiring special attention are that:

- Water should be maintained inside the well during drilling, so that a cave-in does not occur; if a running-sand layer is encountered, slurry should be introduced.
- Drilling should not be too forceful; otherwise there is a risk of breaking the wire or damaging the well pipe.
- The hollow cone should be supported vertically by hand or allowed to lean against the pipe while being lowered.
- When the deep-well pump pipe is being used to straighten the well pipe, the flanges of the pump pipe should not be adjacent to joints of the well pipe.
- Once the pipe-straightening device has been lowered into the well pipe, it should be moved once a day to ensure it does not become lodged inside.

Drilling holes with a bore-bit is also a means to straighten a bent pipe. The main equipment is a wooden straightening device, diesel engine, windlass, slurry pump, bore-bit, and boring rod. The wooden pipe-straightening device is a round stick 18 cm in diameter, 4.8–8 m long so that its length is 2–3 m longer than the bent portion of pipe (Fig. 107).

The procedure is first to connect a 20-cm-diameter bore-bit to a boring rod; next to drill three holes on the vertical plane of the well pipe. The manual rotary drilling method is used, water being pumped via a high pressure tube in the boring rod to the bottom of the holes. The holes are dug to the depth of the bent pipe. The drilling loosens the soil, and the resistance of the soil layers is reduced. The third step is to lower the wooden pipe-straightening device into the well, twisting it continuously so that the pressure straightens the bent pipe. When the well pipe has been straightened, the holes outside the well pipe are filled or sealed with clay, the pipe-straightening device is withdrawn, and the well can be used again.

Sometimes, a pipe must be replaced — the damaged pipe removed first and the new one lowered. One method to prevent running sand from entering the well while the pipe is being replaced is to fill the well with beans contained in 30-cm-long bags whose diameter is the same as the internal diameter of the well pipe. The beans absorb water, and stuff the well. To be effective, this operation should be conducted 24 hours before the pipe is lifted, and the depth of the bean filler should be 1.5 times that of the pipe to be replaced. As in pipe-straightening, soil resistance is reduced if four to six holes are dug around the well pipe; a 16-cm-diameter sharp bore-bit (Fig. 108) is a size suitable for the drilling.

In some areas of China, a crescent-shaped, pipe-lifting tool (Fig. 109) is connected to a boring rod and is lowered into the well. A guiding boring rod, not more than one and a half times as long as the depth at which pipe replacement is needed, is also lowered into the well and left there when the damaged pipe is withrawn. It marks the location of damage. From a new well, the number of pipes that can be lifted in one session is much more than that from an old well. If sand and silt enter the well when the pipe is withdrawn, a 55-cm-diameter, fishtail bore-bit (Fig. 110) can be used to expand the well hole; it will also remove the bamboo strips and other miscellaneous objects inside the well. A 28-cm-diameter cylinder-type, bore-bit may facilitate the joining of the pipes; connected to a straightness-supporting device (Fig. 111), it comes in contact with the pipe inside the well and clears

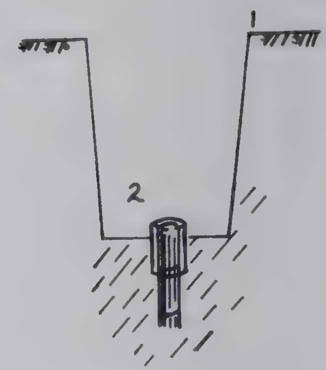


Fig. 102. The working pit and protective casing (1, working pit and 2, protective casing).

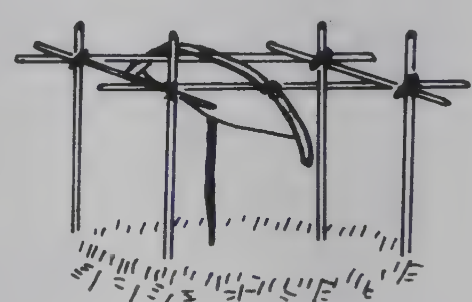


Fig. 103. The working scaffold.


Fig. 104. Hollow cone.


Fig. 105. Hollow cone driven to bottom of bent pipe.


Fig. 106. Pipe being used to straighten well pipe.

Fig. 107. *Wooden pipe-straightening device.*

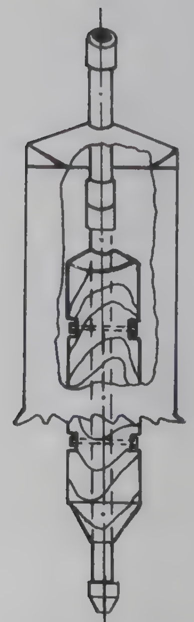


Fig. 111. Cylinder-type bore-bit connected to the straightness-supporting device.

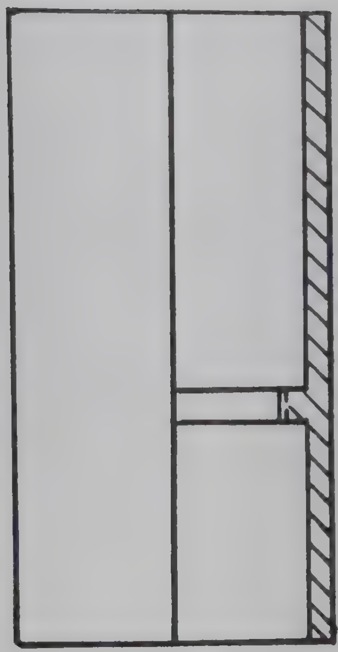


Fig. 112. Reverse screw joint.

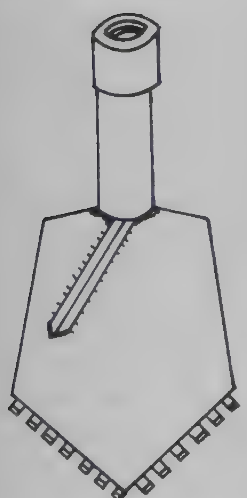


Fig. 108. Sharp bore-bit.

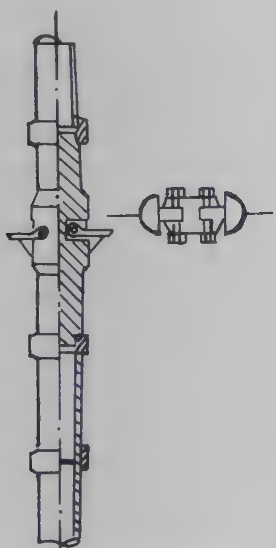


Fig. 109. Crescent-shaped, pipe-lifting tool.

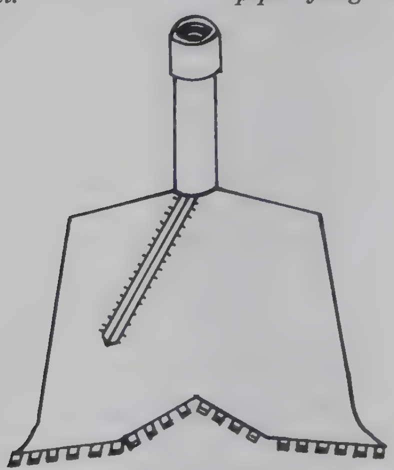


Fig. 110. Fish-tail bore-bit.

the outer surface of the well pipe to a depth of 50 cm, removing all the bamboo strips and miscellaneous objects existing around the mouth of the pipe inside the well.

An iron joint is fixed to the first new pipe that is to be lowered into the well — for concrete pipe, a reverse-screw joint (Fig. 112) and for a cast-iron pipe, a nonscrew joint (Fig. 113). After the pipes are joined, the holes around the well should be filled and sealed with clay.

Sometimes the new pipe is lowered before the damaged one is extracted. This method is possible when a large-diameter well pipe is to replace a small-diameter pipe. As in all other methods, the first step is to locate the damaged area. Then the well is filled with slurry. Next, a 2.5-m-long boring rod is tied to a base plate by palm coir and driven down 3–5 m lower than the damaged pipe. A manually operated scaffold with a suspended hollow cone (Fig. 114) provides the support for the boring rod. The cone is lifted and lowered by galvanized wire.

Well Sealing against Saltwater Entry

In Henshui district, there is generally a saltwater layer (salinity exceeding 2 g/l, often called "bitter water"); the freshwater is often 30 m but may be 200 m lower. Even partial, shallow freshwater layers are covered by a thick layer of

saline water. Sealing off the saline layer, therefore, is the key to guaranteeing good water in the well.

The three main reasons for saltwater entry into a well are that the saltwater layer is not sealed properly with clay (when pumping begins, air pockets outside the well pipe form and allow passage of the saltwater); that poor-quality concrete pipe has been installed or the joints between pipes have not been properly sealed; and that the filter materials exceed the boundary of both fresh- and saltwater so that the latter percolates into the well. The procedures for treating a well in which saltwater has occurred are the same as those for preventing the entry of the saltwater. Sealing can be either external or internal to the well pipe.

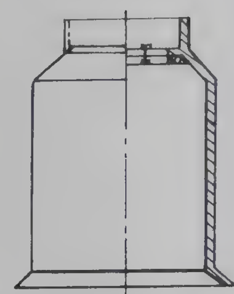


Fig. 113. Nonscrew joint.

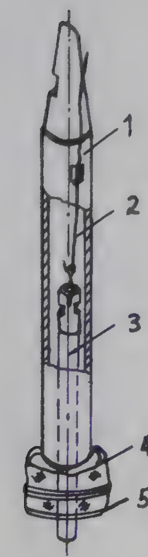


Fig. 114. Apparatus for large-diameter pipe lowering (1, hollow cone; 2, two galvanized wires; 3, boring rod; 4, palm coir; and 5, base plate).

External Sealing

The external sealing method was invented by the well-drilling team of the Chi district and has been used in 18 wells that were contaminated by saltwater. The well-repairing groups of Woo-i district are using this method as well. The steps in the method are to define the saltwater layer; then, use a 33–50-cm diameter, fishtail bore-bit to drill four to six holes around the well pipe on a diagonal to it (the centres of the holes being 50 cm away from the edge of the well pipe and reaching 1–2 m deeper than the saltwater layer); next, flush out the holes with clean water; fill them with clay balls or broken clay lumps, about 2 cm in diameter; and, finally excavate a trench 1.5 m deep and 2 m in diameter around the well pipe, fill it with water, and maintain the water level for 2–3 days to allow the soil layer around the pipe to settle firmly. The trench is then refilled with dirt, and, after 7 days, the well is ready for use.

Matters requiring special attention are the diameter of the bore-bit, which should be at least 33 cm; the distance between the drilled holes and the well pipe, which should be no more than 50 cm; the direction of the holes, which should be diagonal and not parallel; and the type of equipment used to drill the holes — a manually operated scaffold with a suspended hollow cone or a hand-operated auger is suitable because these tools operate at low speeds, are more sensitive to changes in soil layers, and thus are unlikely to damage the well pipe.

Internal Sealing

The well-repairing group of a drilling team in Fu district invented a method of sealing the inside of the well pipe with a plastic pipe and preventing the entry of saltwater. This method is suitable for use in a nonporous pipe in a deep well, when the intrusion of saltwater is caused by improper packing of filling materials, loose joints, or horizontally displaced pipes.

The sealing pipe is approximately 6–9 cm smaller in diameter than the original pipe and is 4, 6, or 8 mm thick. It is 10 m longer than the depth at which saline water is entering the well.

The preparatory steps are to ensure there are no obstructions inside the well; to attach a sealing mechanism to the plastic pipe; and to install a one-way valve within the sealing pipe. Lowering a 108-mm-diameter, 100-mm-long steel pipe into the well is a means to detect obstructions that must be cleared by a steel bore (Fig. 115).

A seal against the entry of saltwater is provided by coir fastened around the plastic pipe by galvanized wire (no. 10–12). About 1.5 kg of good quality (soft, tight) palm coir is sufficient; the end product is a plastic pipe with two coir bowls attached, one near the top and one near the bottom (Fig. 116). Making the coir bowls is simple; three layers of palm coir are wrapped evenly around the pipe and tied firmly by the root with three rounds of the wire. Then the coir tip with the coir root is folded, tied with three rounds of galvanized wire, and fixed to the plastic pipe with four screw nails. Once the coir root and tip are folded, the bottom is formed by hand into the shape of a bowl. The lower end of the bowl is firmly tied with three rounds of wire. Finally, two no. 8 galvanized wires are tied to the bottom of the lower coir bowl and fastened firmly to something outside the well.

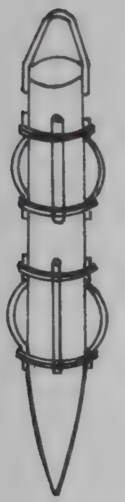


Fig. 115. Steel bore.

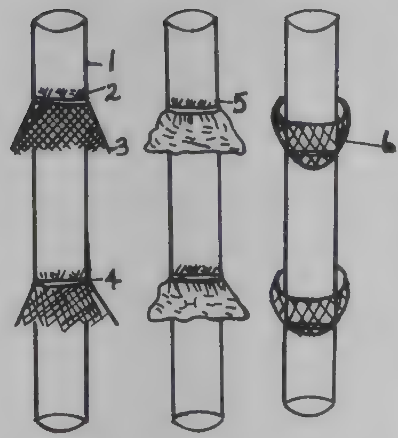


Fig. 116. Forming the coir bowls and attaching them to a plastic pipe (1, plastic pipe; 2, coir root; 3, coir lip; 4, wire; 5, place where the coir lip and the coir root will be folded; and 6, coir bowl).

This final step allows the plastic pipe to be lifted without damage to the sealing mechanism.

The final step in preparation is to install a one-way valve in the pipe. Because the well pipe becomes smaller after the plastic pipe has been lowered into the well, a suction pipe cannot be lowered into the well, and pumping must be carried out directly from the opening of the plastic pipe. Thus, a one-way valve must be installed in it before it is lowered into the well pipe. One method is to heat one end of a plastic pipe and use a round bar to push the one-way valve 0.5 m into the pipe; the diameter of the valve should be 3 mm greater than that of the plastic pipe so that, when the pipe cools, the valve will be firmly fixed. It is of paramount importance that the valve is not inclined inside the pipe.

Installing the plastic pipe is next. The method is to lower the plastic pipe into the well pipe; fill the space between the upper and lower coir bowls with clay. If more than one section of plastic pipe is needed, then only the uppermost section has a one-way valve, and each new section is heated along the bottom, supported by a wooden piston or bowl, and while still hot, inserted 10 cm into the previous section of pipe. The joints are secured by four wooden screws. When all the pipes have been lowered, 50 kg of wet clay balls and 50 kg of dry clay lumps are inserted between the well pipe and the plastic sealing pipe; the clay settles on top of the upper coir bowl and forms a clay layer approximately 2 m thick (Fig. 117). Pumping is not resumed until at least 10 hours later.

Matters requiring special attention are the distribution of the clay, which should be even and continuous; the quality of the clay both in wet balls and dry lumps, which must be pure, the balls 8–12 mm across and the lumps about 10 mm across; the plastic pipe's descent into the well, which should be slow and steady, the pipe being twisted and rotated by hand; the joints between pipe sections, which must be tight; and the screws within the joints, which must not be allowed to protrude into the well.

Since March 1972 the Fucheng district has repaired six deep wells with this method, achieving good results (Table 13).

Silt and Sediment Removal

At times, wells do not produce enough water, or they have a good discharge at the beginning but the discharge steadily declines until it is negligible. The reason is that sand or rocks have blocked the water inlets. The silt or sediment inside the well must be removed. Of the numerous methods currently used in China to deal with siltation, only three are really satisfactory: blowing out the silt through a sealed pipe, removing the silt with two pumps, and cleaning out the silt with a well-washing tool.

The equipment for blowing out silt through a sealed pipe (air-pump method) (Fig. 118) comprises a compressor and air pipe that forces air under high pressure into the well, a sealed pipe, either plastic or iron, that has a wall thickness of

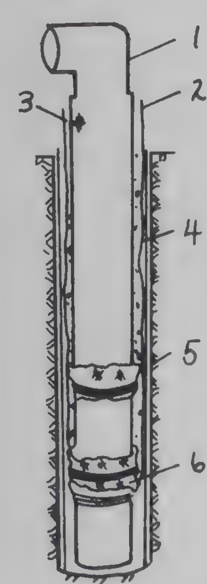


Fig. 117. Internal seal with plastic pipe (1, bend of water pump; 2, galvanized wire; 3, one-way valve; 4, clay ball; 5, upper coir bowl; and 6, lower coir bowl).

Table 13. Comparison of salinity in wells before and after repair.

Team	Depth of leak (m)	Depth of internal sealing (m)	Salinity before repair (g/l)	Salinity after repair (g/l)
Holi	130	140	9	1.2
Shihchuang	20	30	3	0.9
Siliu	110	120	6	1.6
Liunan	120	130	5	0.8
Chautun	70	100	7	0.7
Yangsan	40	70	5	1.2

5 mm and a diameter of 100 mm, a pipe-holding tool, and a T junction.

First, a scaffold is erected and a winch attached so that the sealed pipe can be lowered into the well to 1 m above the silt surface. The upper part of the sealed pipe is connected with a T junction, and an iron pressure cap and a circular rubber washer are mounted on the vertical outlet of the T junction to cover the upper opening of the sealed pipe. The air pipe is connected to the vertical opening of the junction so that water and sand can flow out through the horizontal outlet. A pressure tube connects the compressor to the air pipe. When the compressor is switched on, air under high pressure enters the sealed pipe and forms air bubbles in a water–air mixture. The specific gravity of this mixture decreases as the bubbles increase, and its volume gradually expands; the water level inside the sealed pipe rises until it reaches the T-junction outlet; water flows out, bringing up sand and silt from inside the well. The sealed pipe is lowered gradually until all the silt inside the well is removed, and the water being pumped from the horizontal outlet is clear.

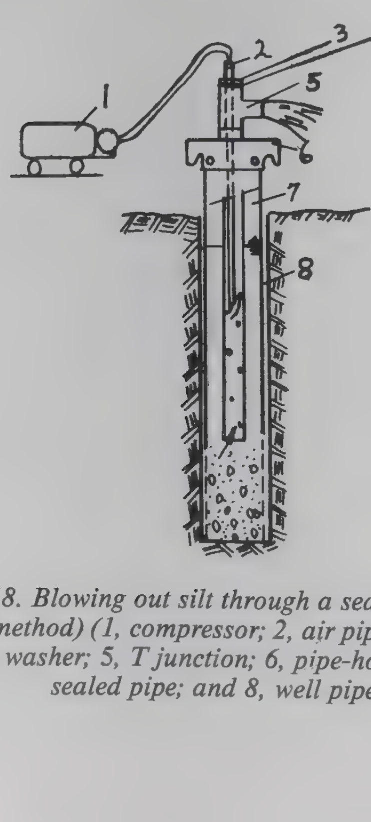


Fig. 118. Blowing out silt through a sealed pipe (air-pump method) (1, compressor; 2, air pipe; 3, pressure cap; 4, washer; 5, T junction; 6, pipe-holding tool; 7, sealed pipe; and 8, well pipe).

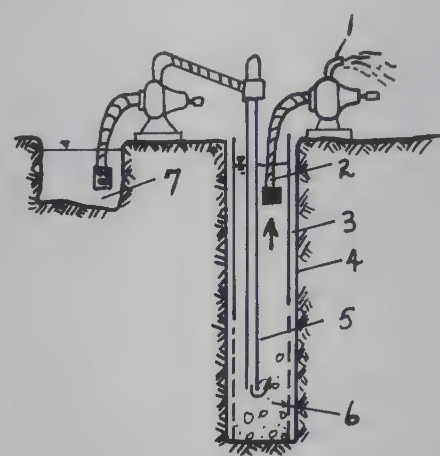


Fig. 119. Cleaning out the silt with two pumps (1, centrifugal pump; 2, suction pipe; 3, well pipe; 4, well wall; 5, delivery pipe; 6, silt and sand; and 7, reservoir).

Practical experience has shown this method to be efficient and time-saving, requiring only 1–2 days. Although it is generally used in deep wells, it is also applicable to shallow wells. Since autumn 1971, Woochiang district has used this method to clear 187 silted wells, after which 175 began to function properly (93%); 156 were silted with sand and 19 with filter materials. For example, a 260-m-deep well built in 1969 was silted with filter materials to a depth of 110 m; there was no discharge whatsoever. The damaged pipe was repaired, and the silt-blowing method was used to clear the filter materials. The well now produces enough water to supply a 5-inch (13-cm) pump.

Matters requiring special attention are the depth to which the sealed pipe is lowered, which should be far enough away from the silt surface so that the water flows freely but close enough so that silt is extracted; the depth to which the air pipe is inserted into the sealed pipe, which should be only enough to ensure good air pressure; and the straightness of the well pipe — if the pipe is not perfectly straight, this method cannot be used.

Clearing the silt with two pumps is a method invented by the peasants in Lauyang district; it uses a 4-inch (10-cm) centrifugal pump, which sends clean water into the bottom of the well through a 3.5-cm diameter water pipe, and another 8–10-cm centrifugal pump to pump out the well water (Fig. 119).

The pumping of clear water brings up the silt from the bottom of the well. The sand is washed up within the range of the suction head of the second centrifugal pump, which pumps it out. The delivery pipe is gradually lowered, as the sand is continuously being pumped out. It is important that the air-delivery pipe is not too near the silt surface; otherwise, the pipe opening may become blocked. Ideally, it should be 30–40 cm away from the surface of the silt. Substituting a slurry pump for the clear-water pump or slurry for the clear water is more efficient, as the water pressure and its capability to bring up silt and sand are increased.

This method is suitable for shallow or medium-depth wells. The operation is easy, and the installation is simple. Normally, three or four people can carry out the task; compared with the labour required to erect a scaffold and a hollow cone to bail out the silt, the method is labour-saving, and the risk of damage to the well pipe is low. It usually takes 2 days to clear 20–30 m of silt. This method has been used in Lauyang district to clear 54 wells, the deepest of which was 184 m, and the results were good. In Anping district, a similar method was used to clear more than 30 wells.

Clearing silt with a well-washing tool was invented by the well-repairing unit of Gin district. Operation is easy and the structure simple. It produces good results in shallow wells. The equipment consists of a jet gun, "jet head," wire ring, and control device (Fig. 120). Also, a scaffold, pulley, a rubber tube, a centrifugal pump, and several sections of pipe are required.

The jet gun is two pieces of steel pipe welded together, the upper one with a diameter of 110 mm and the lower one with a diameter of 76 mm. The jet head is a piece of 60-mm-diameter steel pipe welded on the lower end of the jet gun. The main nozzle is the lower end of the jet head, having a diameter of 60 mm. There are 10–15 small holes or nozzles 15 mm in diameter on the upper part of the jet head.

The control device is two 60-mm-diameter steel pipes welded on the middle of the jet gun, at an angle such that the whole apparatus is narrower than the well diameter. The control device is a support to prevent the jet head from burrowing into the silt. The preparatory steps are to excavate a water-recirculation drain and two water-storage ponds away from the well; erect a well scaffold with a pulley on top to lift a rubber tube; connect a water-delivery pipe (10 cm in diameter and the length of the well) to the jet gun and the discharge pipe of the centrifugal pump; and fasten the cable of the winch onto the wire ring on the jet gun through the pulley. Dry clay is mixed with water to form a slurry that is pumped through a rubber tube attached to the well-washing tool. The sediment is brought up by the buoyant force of the slurry. The rubber tube is lowered continuously into the well as the work progresses. Once the bottom of the well is reached, the well is washed with water until clear.

Matters requiring special attention are the well-washing tool, which should be firmly joined to the rubber tube; the nozzles, which should be free from obstruction; the speed with which the rubber tube is lowered, which should be slow and continuous; and the sand and silt settling on the water-recirculation drain, which should be removed periodically.

This method was employed in Chin district in more than 20 wells, and the results were very good. It has also been used to wash the walls of the wells; the water spurting out through the small nozzles cleans the filter pipe and increases the well's discharge. In one case, a 39-m-deep, "pot-drilled" well was supplying only enough water for an 8-cm pump; this method took 2 h to clear the well, and now the discharge is sufficient to supply a 10-cm pump.

Salvaging Equipment

Sometimes due to negligence during construction, pumping facilities are not properly installed, and during use, the pump's intake pipe, suction pipe, or some other part falls into the well. Or due to poor maintenance at the well opening, rocks, bricks, tiles, and tools occasionally fall into the well. Tools to salvage such equipment have evolved from practical implementation. One tool is designed especially to salvage the intake pipe of a centrifugal pump. It is made according to the special features of a water-pump intake pipe, i.e., the upper part is small and the lower part is large.

The tool consists of a rounded steel bar and movable hooks (Fig. 121); a handle is welded to the upper part of the bar and is connected to a cable; the lower part of the bar is sharp, and the middle has a rectangular groove. Two movable hooks are fixed to two small pivots in this groove such that the hooks can be moved up and down on the pivots. A rubber band is attached to the lower ends of the hooks and pulled tight so that the

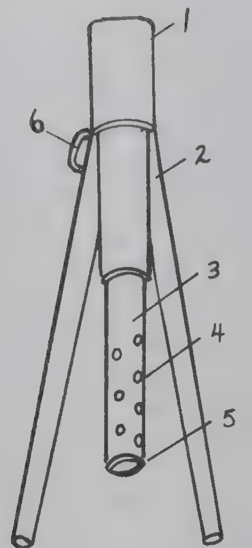


Fig. 120. Well-washing tool (1, jet gun; 2, control device; 3, "jet head"; 4, small nozzle; 5, main nozzle; and 6, wire ring).

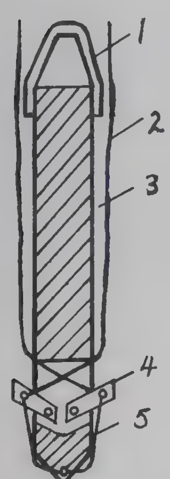


Fig. 121. Salvage tool for a water-pump intake pipe (1, handle; 2, guiding cord; 3, steel bar; 4, movable hooks; and 5, rubber band).

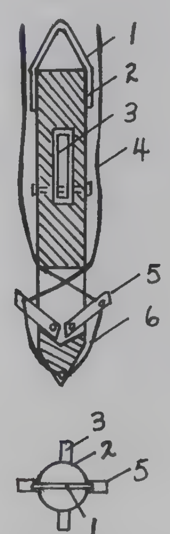


Fig. 122. Rubber-tube salvage tool (1, handle; 2, rounded steel bar; 3, movable hooks; 4, guiding cords; 5, movable hooks; and 6, rubber band).

hooks are extended outward. Each hook is tied to a guiding cord and folds up when the cord is pulled.

The tool is gradually lowered on a cable into the well. When the sharp end of the bar enters the upper part of the intake pipe, the two movable hooks fold up because of the pressure from the internal wall of the pipe. When the salvage tool reaches the lower part of the intake pipe, the rubber band pulls the movable hooks outward. Because the width of the extended hooks is greater than the internal diameter of the upper intake pipe, the pipe is lifted when the salvage tool is withdrawn from the well. If the intake pipe is lodged inside the well, the salvage tool is withdrawn without the intake pipe, the guiding cords being pulled so that the hooks fold back into the groove.

This tool has been extensively used in China, salvaging more than 20 centrifugal pump intake pipes in Hensui district, 4 in Fu district, and 12 in Shen district. The operation generally takes 1–2 h. Another tool used in China is the rubber-tube salvage tool. The basic structure is similar to that of the water-pump, intake-pipe salvage tool. The only difference is an additional pair of movable hooks (Fig. 122). Both pairs of hooks are fixed on the rounded steel bar. This tool has been used by Hensui district to salvage six rubber tubes.

If wire or cable falls into the well, it can be salvaged with a piece of rounded steel bar that has had three hooks welded to its centre (Fig. 123). The position of the cable inside the well is determined first; then the hook is lowered into the well on a wire. When the hook has caught the cable, it should be lifted immediately, bringing the cable with it. This hook has been used by the well-repairing group in Fu district to extract a 180-m-long steel cable.

The spiral salvage tool is mainly for pincers, axes, hammers, bricks, etc. It is a rounded steel bar reinforced by a spiral bar wound five times around it (Fig. 124). When used to salvage equipment in a 200-mm-diameter well pipe, it usually has an upper diameter about 100 mm and a lower diameter about 180 mm. The spiral salvage tool is lowered into the well on a boring rod and is

Fig. 123. Hook for salvaging wire and cable.

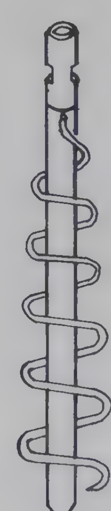


Fig. 124. Spiral salvage tool.

Fig. 125. Piercer.

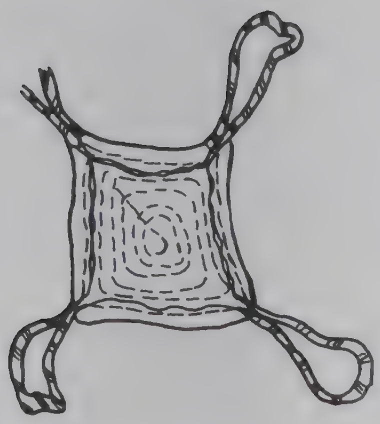


Fig. 126. Canvas sack.

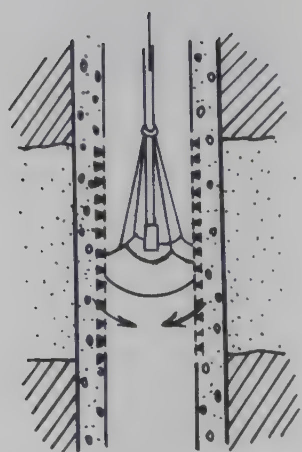


Fig. 127. Canvas-sack well washing.

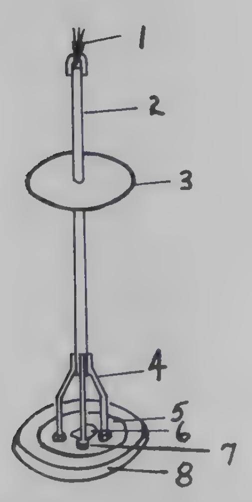


Fig. 128. Piston (1, steel wire; 2, boring rod; 3, rubber ring; 4, iron bar; 5, circular iron plate; 6, valve; 7, female thread; and 8, rubber mat).

manipulated so that the object enters the spiral from the bottom. The boring rod is rotated carefully until the object is cramped firmly by the spiral reinforcement bar.

A piercer (Fig. 125) breaks bricks and rocks that have fallen into the well into pieces so that they settle to the bottom. It is a rounded steel bar with one end sharpened to a point and topped with a screw. The piercer is attached to a boring rod and lowered into the well via a scaffold. It is rotated so that it bores through any obstructions.

Increasing Well Capacity

Some wells have no damaged pipes, no sand inside, yet still give insufficient discharge to supply a pump. The reasons are mainly improper handling of the slurry during construction, incomplete or delayed washing (developing) of the well after construction, and leaving the well in disuse for a long time, in which case the slurry clogs up the filter pipe and fills the voids in the sand layer so that water cannot enter the well. Two methods have been designed to deal with these problems and have achieved good results. One is the canvas-sack well washing method, which has been used successfully by the well-drilling team of Shen district for more than 80% of poorly discharging wells. The only disadvantage is that the canvas sack wears out quickly.

The canvas sack comprises three square pieces of canvas that are bigger than the internal diameter of the well pipe. These are stitched together, one on top of another; two pieces of rope are sewn to the corners of the canvas so that they form an "X" (Fig. 126). The ropes are attached to a short boring rod, which is raised and lowered repeatedly until the well is washed.

As it is lowered, the canvas sack folds together under the resistance of the water and opens when it is being lifted; the water on top of the sack forms a vacuum under the sack for a short time, and the water in the water-containing layer rushes into the vacuum through the filter materials, bringing a lot of sand with it. The process is repeated until the well's discharge is improved (Fig. 127).

Matters requiring special attention are the quality of the canvas sack and the hemp ropes, which should be reliable; the position of the boring rod, which must be in the centre of the canvas sack; the speed at which the boring rod is lowered, which should be slow; and the speed at which the rod is lifted, which should be fast.

The well-repairing group of Lauyoung district has increased well discharge by installing a valve piston on a boring rod and using it to remove

slurry and sand particles from the well. The principles are similar to those in the canvas-sack well-washing method. The method is suitable for wells with a good sand layer but not for horizontally displaced well pipes.

The piston consists of five layers of thin rubber sheet formed into a circular rubber mat with a diameter of 3–4 cm larger than the internal diameter of the well pipe and sandwiched between two circular iron plates, the upper one 14 cm and the lower one 16 cm in diameter. A valve is installed at the centre. Three 1.5-cm-thick, 0.5-m-long iron bars joined by a screw joint at one end form a tripod to hold the iron plates. The other ends of the bars are welded to a 5-m-long boring rod, and an iron ring is welded on the top. A rubber ring is fixed on the top portion of the boring rod and just below the iron ring (Fig. 128). A frame is made from four pieces of 14-cm-thick and 1-m-long rounded sticks; an iron plate is attached at the centre of the frame to support a pulley mounted directly over the well. The additional equipment needed is a windlass to lift and lower the piston; an intermediate unit to control the revolution speed; and a 10-hp diesel engine or electric motor to drive the piston via the intermediate unit and the windlass. When the piston is moving, the water inside the well becomes turbid; then the piston is stopped and the turbid water is pumped out. These procedures are repeated until the water is clear and the discharge sufficient.

Matters requiring special attention are the alignment of the pulley, the cable, and the piston, which must be straight; the lifting speed for the piston, which must be maintained at 0.1–1 m/s; the type of well pipe, which must be porous (filter pipe); the cable, which should be checked for weakness regularly; and the number of layers in the piston's rubber mat, which may be modified if the piston is difficult to move or moves too freely.

From June 1972 to November 1972, the well-repairing group of Lauyoung district used this method to repair 40 wells.

Chapter 11

Well-Repair Methods in Shantung Province

In Shantung province, modified well-repairing instruments have been successfully developed. They have proved to be good quality, highly efficient, economic, and simple. To date, more than 100 wells have been repaired.

The three-headed probe (Fig. 129) is a tool used by the well-repairing group in Shantung province to locate damage in a well and to find out its cause. Formerly the singled-headed probe was used, but it often bypassed the damage, was difficult to operate, and was not efficient. The three-headed probe was devised after much testing, improvement, and modification. It consists of three probe heads, each topping a series of two sliding cylinders, and two probe springs. The probe heads and cylinders are mounted on a frame attached to a rod; a rope connected to the apparatus controls its spring action. The sliding cylinder with the probe fits inside the second sliding cylinder. The use of more than one sliding cylinder allows the apparatus to accommodate a range of well-pipe diameters. The spring action pushes the probe head into damaged areas, the probe head being automatically pushed into a hole or disconnected joint by the spring. Thus, the depth of damage can be easily recorded. If the probe can only be moved to a limited degree, the damage is a hole; if it can be turned completely, the pipes have been disconnected. The sliding rope is pulled tight so that the probe head is contracted into the sliding cylinders and the search for additional damage can be resumed.

Bamboo and Coir-Bark Casing

A bamboo and coir-bark casing has been found useful in well-wall repairs. It is more effective than normal casings that reduce the cross-sec-

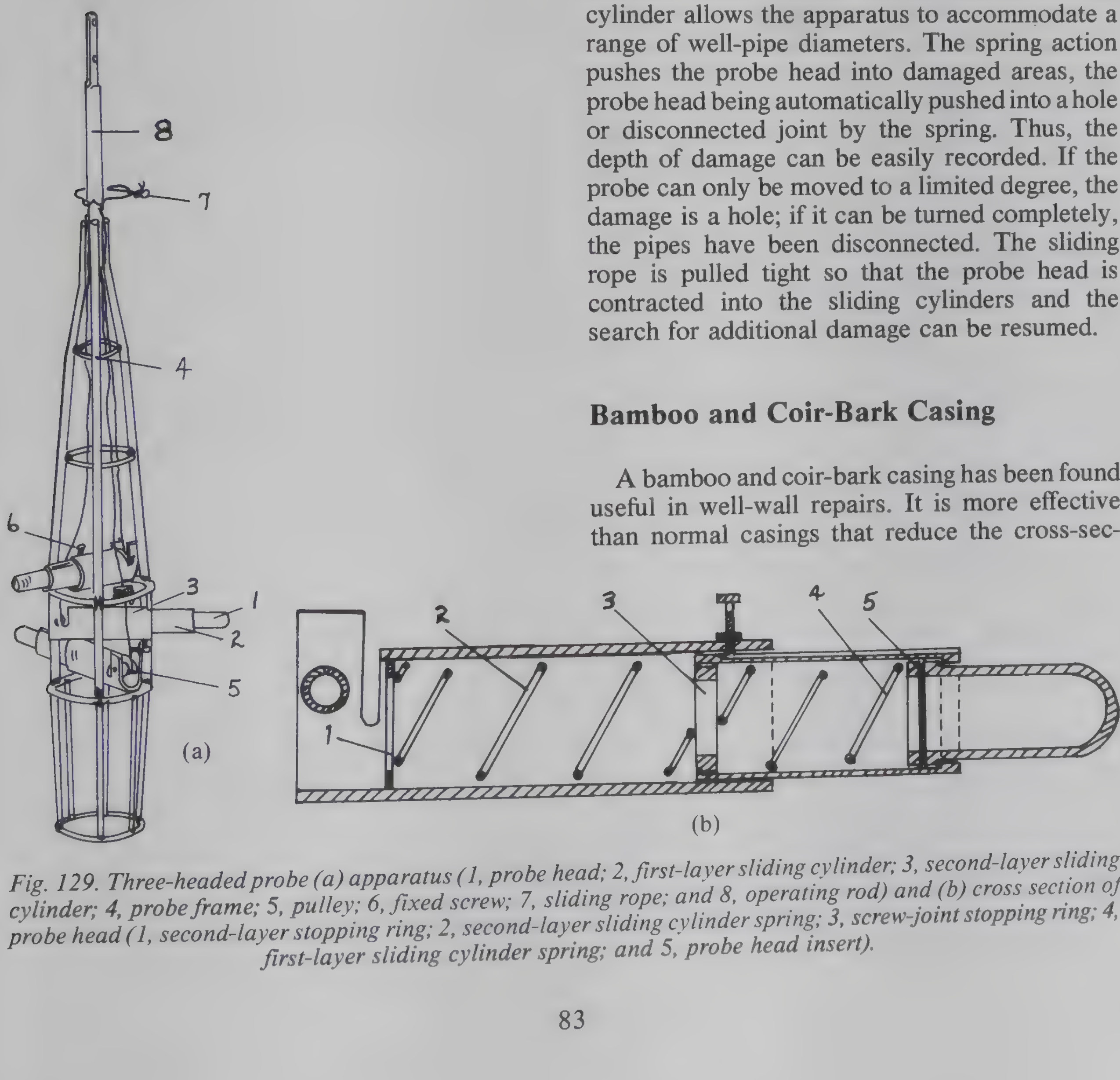


Fig. 129. Three-headed probe (a) apparatus (1, probe head; 2, first-layer sliding cylinder; 3, second-layer sliding cylinder; 4, probe frame; 5, pulley; 6, fixed screw; 7, sliding rope; and 8, operating rod) and (b) cross section of probe head (1, second-layer stopping ring; 2, second-layer sliding cylinder spring; 3, screw-joint stopping ring; 4, first-layer sliding cylinder spring; and 5, probe head insert).

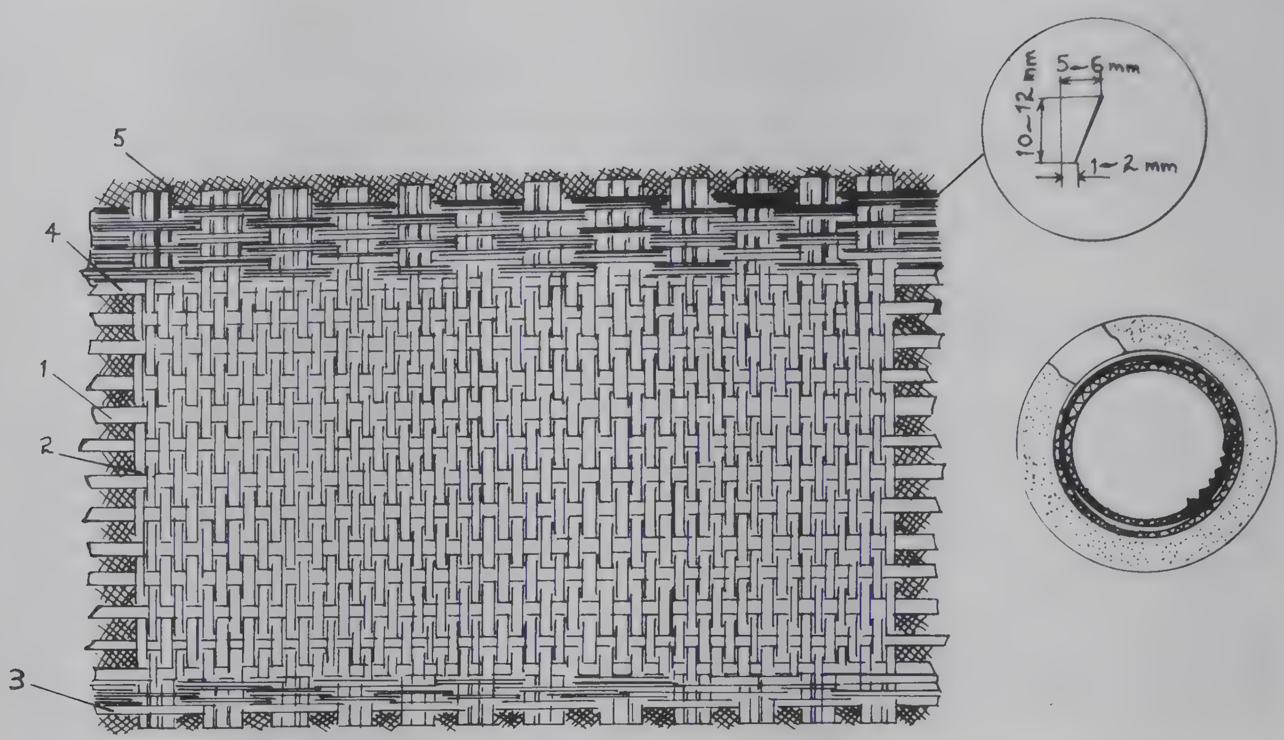


Fig. 130. Bamboo and coir-bark casing (1, horizontal bamboo strip; 2, vertical bamboo strip; 3, flat bamboo plank; 4, trapezoidal bamboo plank; and 5, coir bark).

tional area inside a well and, therefore, the water flow. It is flexible, expanding and assuming the required shape once it has been lowered into the well. It has been modified and improved during use and has proved durable.

The steps in making the bamboo and coir bark casing are to calculate the area of casing needed to repair the well pipe (this figure is calculated from the well diameter and the depth of damage); arrange 1.5–2-cm-wide bamboo strips so that they are horizontal and vertical like a knitted mat the size of which is equal to the area of casing needed; at one end of this skeleton, attach six trapezoidal bamboo planks (upper base 1–2 mm, lower base 5–6 mm, height 10–12 mm) and at the other end attach four flat bamboo planks (width 10 mm, thickness 3–4 mm); finally, reinforce the matting with two or three layers of coir bark, attached with string or galvanized wire (no. 20). This forms the planar surface of the casing. It is soaked in water for 1–2 h before being used so that it is pliable and then is rolled to form the casing. One end of the bamboo strips is matched with the "teeth" formed by the trapezoidal bamboo planks. The bamboo strips can slide in only one direction, the casing being allowed to expand but not contract; when the casing expands, it is wedged against the well wall (Fig. 130). Installation can be carried out with the help of a well-repairing device — a specially made tool that operates like an umbrella (Fig. 131).

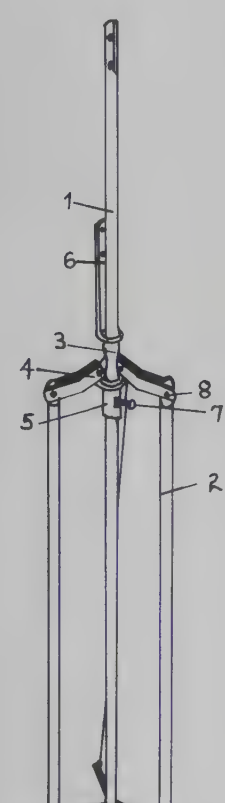


Fig. 131. Well-repairing device (1, pulling rod; 2, casing-support frame; 3, expanding and contracting sliding case; 4, prop arm; 5, prop-arm supporting case; 6, supporting rod; 7, supporting-case screw; and 8, prop-arm screw).

The well-repairing device is contracted and the protruding bamboo strip at one end of the bamboo and coir-bark casing inserted into the device. The casing is rolled tightly around the frame and tied with string; galvanized wire (no. 12) is attached to the string and will be used later to sever the string. The well-repairing device is contracted and lowered into the well, one end of the wire being kept at the well opening. When the device is at the level of well damage, the wire is pulled sharply so that the string is severed and the casing installed. Then, the well-repairing device is contracted and withdrawn.

The three-headed probe, well-repairing device, and the bamboo and coir-bark casing are simple devices. They can be made easily and inexpensively.

Iron Sealing Pipe

The iron sealing pipe (Fig. 132) has proved suitable for repairs of leaks in wells, takes little time to install, and is both economic and simple to produce. It is made from a 1–1.5-mm-thick iron sheet rolled to form 10–12.5-cm-diameter pipes, the joints of which are connected by rivets; bitumen is applied to areas where leakage may occur. The 10–15-m-long iron pipe is lowered into the well, with a tripod, and both the lower opening of the bottom valve and the upper part of the iron pipe are sealed. This method is very popular and is inexpensive.

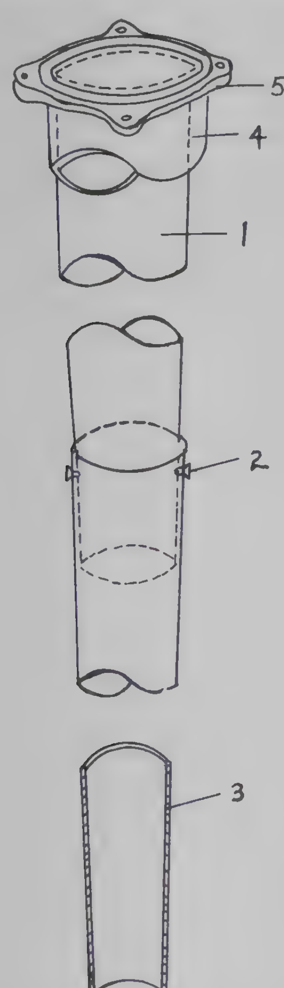


Fig. 132. Iron sealing pipe (1, iron pipe; 2,rivet; 3, bitumen; 4, original pipe; and 5, original plate).

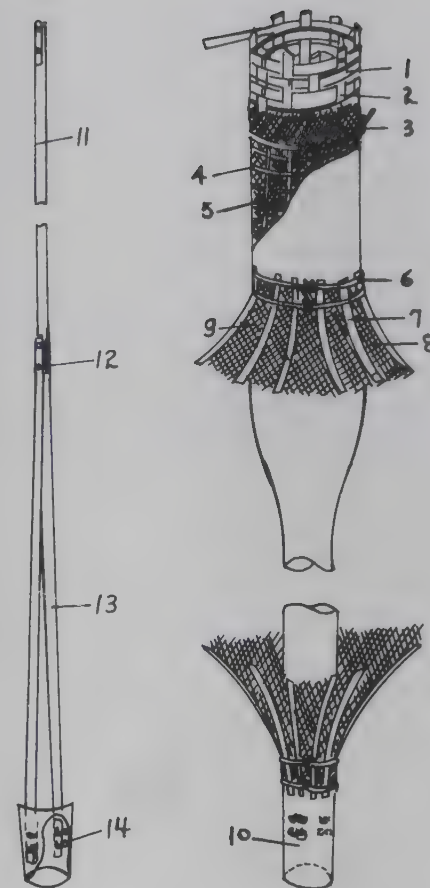


Fig. 133. Conical bamboo pipe (1, horizontal bamboo strips; 2, vertical bamboo strips; 3, coir bark; 4, externally wrapped horizontal bamboo strips; 5, externally wrapped vertical bamboo strips; 6, galvanized wire [no. 10]; 7, coir bark [bamboo strip]; 8, coir bowl [coir bark]; 9, wire [no. 20]; 10, conical iron pipe; 11, pulling rod; 12, screw; 13, guiding prong; and 14, insert ring).

Conical and Hollow Bamboo Pipes

If horizontal displacement in well pipes exceeds 8 cm and the well continues to be used, silt will enter the well pipe and directly affect the discharge of the well. The conical bamboo pipe is an economic and simple solution to the problem.

The conical bamboo pipe (Fig. 133) is 3.5–4 m long, is composed of bamboo strips, and has two pieces of galvanized wire (no. 10–20) as rein-

forcement. The diameter of the pipe is based on the degree of horizontal displacement. On both ends of the pipe, bamboo bowls are attached, facing opposite directions. For installation, a conical iron pipe, 1–1.5 mm thick, made from sheet metal is fixed inside the bamboo pipe with galvanized wire. Then, a guiding prong is placed in an insert ring, and an insert prong is connected to the pulling rod, which will deliver the pipe to the position of displacement. When siltation occurs at joints of well pipes or at holes, a hollow bamboo pipe can be used for repair, giving good results. Made of 4-m-long bamboo strips, the pipe's diameter is about 12 cm; the outer part of the pipe is wrapped with two or three layers of coir bark and tied with thick bamboo. The 4-m-long bamboo pipes are joined by 1-m-long iron pipe (tied with no. 10 galvanized wire) so that the total length of the pipe is equal to the depth of the well. The whole length of the pipe is reinforced by galvanized wire (no. 10–12).

The bottom part of the pipe is attached to iron pipe, 1.1–5 mm thick; two symmetrical insert rings are suitable. The guiding prongs pass through the insert rings and connect to the pulling rods; this apparatus is lowered into the well, and the pulling rods are withdrawn. This method of repair costs about 50 yuan.

Appendix 1

Determining Residual Chlorine

Potassium Iodide Colorimetry

The reagent for potassium iodide colorimetry is starch–potassium solution: 2 g soluble starch (or normal starch) is dissolved in 100 ml distilled water, boiled, and allowed to cool to room temperature; 8 g potassium iodide (KI) is added, and the mixture is agitated until the KI is thoroughly dissolved. The solution should be stored in the dark.

The procedure is to add five or six drops of the solution to a 100-ml sample of water disinfected with chlorine (e.g., bleaching powder) and mix carefully. Blue indicates residual chlorine; light blue indicates the appropriate chlorine content.

Append. Table 1. Relationship between smell, colour, and residual chlorine in DPD colorimetry.

Residual chlorine (mg/l)	Smell of chlorine	Colour
0.1	Slight	Light yellow
0.2	Easily detectable	Yellow
0.5	Obvious	Yellow
0.7–1.0	Strong	Deep yellow
>20	Strong	Brown

Dimethyl-Paraphenylene-Diamine-Hydrochloride (DPD) Colorimetry

The reagent for dimethyl-paraphenylene-diamine-hydrochloride (DPD) colorimetry is a solution of 10 ml hydrochloric acid, 90 ml distilled water, and 0.1 g DPD.

The procedure is to add three to five drops of the solution to a 5-ml water sample. Yellow indicates residual chlorine (Append. Table 1).

Appendix 2

Determining the Chlorine Required

If adequate chlorine is added as treatment for water, there should be residual chlorine in the water. A test for residual chlorine should be run (Appendix 1) but not until at least 30 minutes after the chlorine application. One method of determining how much chlorine is needed is to compare the effects of adding different amounts of chlorine to small quantities of the water to be treated and then to extrapolate the amount that provides suitable residual chlorine to the amount of water to be treated.

The equipment needed is five 100-ml beakers (or porcelain bowls), five glass rods, 100-ml measuring cylinders, 10-ml graduated pipettes, and droppers. The procedure is to dilute 1 ml of 1 : 100 (w : v) bleaching solution (1 g bleaching powder : 100 ml distilled water) in enough distilled water to make 100 ml; line the beakers on the table and label them (e.g., 1, 2, 3, 4, 5), each containing a 100-ml sample of water; with a pipette, add 2, 3, 4, 5 ml of the bleaching solution into beakers 2, 3, 4, 5, respectively; agitate with glass rods, and drop three drops of starch–potassium iodide solution (Appendix 1) into each beaker and agitate. Within 5 minutes, the chlorine will have liberated the iodine from the solution, and the treated water will be blue. The amount (ml) of bleaching powder solution added to the beaker with a light-blue solution is the amount of bleaching powder in g/m^3 one needs to treat the drinking water. For example, if a light-blue solution is obtained when 4 ml of bleaching powder solution (1:10 000) is added, then 4 g bleaching powder is required to treat 1 m^3 water. If the free available chlorine in the bleaching powder is 30% by weight, then the chlorine required is 1.2 g/m^3, ($4 \times$ 30%), or 1.2 mg for each litre of water.

Appendix 3

Determining Water Quality

Some methods have been developed to test water quality in rural areas where no laboratory or equipment are available. These include tests on colour, odour, taste, temperature, settleable solids, and pH. Pure water is colourless, odourless, and tasteless.

If water placed in a white container is yellowish, it may contain a large quantity of decayed organic matter. A reddish yellow suggests a high iron concentration, and blue suggests a high hydrogen sulfide concentration.

If a sample of water shaken in a stoppered bottle has an odour, it should be heated to 60° C in a water bath and smelled again. If it still emits odours, the source should be further investigated before being used.

To test for taste, one heats a sample of water to 60 °C in a water bath, then tastes it. If the water contains a high quantity of organic matter, its taste may be sweet; a high concentration of sodium chloride will produce a salty taste; hard water will have an astringent effect.

Water temperature is often a good indicator of contamination. Any sudden change in temperature suggests that the water is contaminated.

A test for settleable solids is to let a sample of water stand overnight, pour the water, with care not to disturb the sediment, into another bottle, heat the water in the new bottle to 100 °C, let it stand till cool, and then observe the sediment. The second sediment is the partially soluble mineral sediment and is indicative of water quality.

Another test is to drip a few drops of sample water onto white paper and let them dry. The less the trace of watermarks, the better the quality of water.

If the pH of sample water is outside the range 6.5–9, the water may be contaminated.

Appendix 4

Quality Standards for Domestic and Potable Water Supplies[1]

These standards are an edited version of the *Quality Regulation for Domestic and Potable Water Supplies*, which was published in 1959 by the Ministry of Health and the previous Ministry of Building. The new standards apply from 1 December 1976.

The standards are controlled by the Ministry of Health; technical aspects will be explained by the Health Department of the Chinese Medical Institute.

In this edition, a section on general provisions has been introduced; it illustrates the purposes, significance, and application of the standards. Also, a section on the quality requirements for water supply has been added, and it stresses the importance of selection of a water source in urban and rural developments, providing for both long-term and short-term requirements.

All units are advised to review the results and problems in executing these standards. Comments would be appreciated for the benefit of future editions.

General Provisions

The reason for establishing these standards (Table 1) is to put into effect a policy of "prevention first," to guarantee that the quality of domestic water supply fulfills the health requirements and thus to protect our people's health.

In applying these standards, water supply authorities, planning authorities, design authorities, etc. should insist on self-reliance and on a combination of traditional and Western methods. These standards should be competently adopted and seriously adhered to. Health departments at all levels should examine and supervise the application of these standards.

When new waterworks are built or when existing works are being expanded or rebuilt, responsible departments should advise on source selection, should check planning and design, and should approve schemes with care.

Source selection, quality examination, and management of individual supplies are carried out by production teams or residential committees. All such units should encourage people to participate in protecting the water sources and in preventing contamination.

These standards are applicable to both rural and urban domestic water supplies and both individual (including private installations) and piped supply systems (Table 1).

For piped supply systems, besides the necessary treatment plant, disinfection facilities should be installed, regardless of the source. For systems that transmit groundwater to the user directly without treatment, equipment should be installed to remove grit and turbidity if necessary. Facilities for water storage, transmission, and distribution must be carefully protected from contact with sewerage networks.

The raw materials used for treatment plant construction and chemicals used for water purification should not contaminate the water supply.

Independent, private water supply systems should not be connected to the urban water supply systems. In special cases when it is necessary, such a connection should be approved by the authority of health and water supply. The connection point should be carefully situated and effectively made; even more effort than otherwise should be put into maintenance, management, and protection of the water.

In a piped supply system, the authority should put considerable effort into the management of the facilities for water collection, purification, storage, distribution, and transmission. Rules and operation regulations should be established, regarding effective control of overflows, disinfection, cleaning, waste discharge, examination, and testing so that the water quality is guaranteed.

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[1]These standards were published and distributed in China in 1976 under the auspices of the Ministry of Health, Ministry Series 139 and an abridged version has also been made available, Hygienic and Health Series 310.

In rural areas, greater emphasis than in the past should be placed on the hygienic control of domestic water supply. Hygienic regulations should be laid down for wells, riverbank filtering wells, sand filters, simple water supply systems, and springs. Adequate measures should be adopted for proper maintenance and management.

Source Selection

In selecting sources, both long term and short term, authorities should consider village developments and city planning. Current data on quality, hydrology, and hydrogeology must be taken into account. Sanitation and cleanliness around the water catchment area and the surroundings and the absence of endemic diseases are important criteria. The source should be sufficient in quantity and quality and be easy to protect. Groundwater should be used in preference to other supply sources. The water catchment site should be upstream from city or industrial development.

The quality of raw water for domestic supplies is determined by:

- The number of *Escherichia coli* in the water, which should be fewer than 1000/litre on average if chlorination is the only disinfection available; the number of *E. coli* can be 10 000/litre on average if both purification and disinfection processes are available;
- The physical and chemical quality, which should conform to the standards (Table 1);
- The toxicological levels, which should conform to the standards (Table 1);
- In areas where goitre is endemic, the iodine concentration; and
- The presence of harmful substances not included in the quality standards (Table 1).

If the source quality does not conform to the standards and if there is no alternative, the project should be approved by the department of health of the province, city, or autonomous region. Alternative treatment methods should be considered in association with the department so that the quality of the water can be improved.

Source Protection

The source for domestic water supply should be in a protected area. For piped supply systems, the protection measures and the size of the area should follow the requirements for:

Surface Water

- Within a radius of 100 m of the catchment point, no boating, swimming, fishing, or other activities that could contaminate the water are permitted. The boundary should be clearly marked.
- Within 1000 m upstream and 100 m downstream of the catchment point, no industrial or domestic wastewater should be discharged into the source; within the protected area, no solid waste material may be dumped, and no harmful chemicals may be stored; use of the protected area as a harbour for loading or unloading refuse, excreta, or toxic chemicals is not permitted; no industrial or domestic wastewater may be used for irrigation in the area; no residual or highly toxic chemical may be used on fields that drain into the protected area; and no grazing is permitted.
- No residential areas, livestock, or husbandry areas; seepage latrines; seepage pits should be constructed or planned within 10 m of pumping stations, sedimentation tanks, or final water tanks at waterworks or private installations.
- Good hygienic conditions and tree planting should be planned.

Groundwater

- The size of the area protecting a catchment depends on hydrogeologic conditions, method and structure of the catchment, and sanitary conditions of the surrounding areas. Protection measures should be carried out as for surface water.
- Within the effective areas of an individual well or a group of wells, no industrial or domestic wastewater should be used for irrigation and no residual or highly toxic chemicals should be used; no seepage latrines, seepage pits, or solid waste dumps may be constructed; no drainage of wastes should be allowed; and no disruption of deep soil strata should be permitted. If the water-bearing stratum is not exposed at the surface or is not recharged by adjacent surface water, the size of the protected area can be reduced somewhat. Protection limits for a water-catchment facility, the effective radius, and water-quality protection methods for groundwater should be studied and determined by the water-supply authority in conjunction with hydrogeologic and public health departments.
- For the area around water-treatment works, the requirements for surface water sources should be met.

Private water supplies from groundwater should be protected from pollution due to seepage latrines, seepage pits, excreta pits, refuse heaps, and solid

waste heaps, none of which should be within 20–30 m of the well. Adequate sanitation systems should be constructed.

When the construction, expansion, or reconstruction of a piped supply system or a private water system is undertaken, the design unit should fulfill all these requirements. When starting the final design, the planners should submit details of the protected area, protection measures, and completion guidelines for the project to the local health authority for approval.

For the protection areas of existing piped supplies and waterworks, consultation should be made with the local health authority and a plan submitted for improving the environment. After approval by the local government body, the plan should be completed in due course. For private water supplies, depending on the circumstances, the health authority may identify the protected area required.

Beyond 1000 m from the catchment point of a surface water source, any discharge of industrial and domestic wastewater should fulfill the requirements of the *Industrial Three-Wastes* [liquid wastes, solid wastes, and gaseous wastes] *Discharge Preliminary Standard* and the *Industrial Design Sanitary Standard*. Any wastewater from health, medical, scientific, and veterinary facilities that may contain pathogens must be fully disinfected before being discharged. The quality of water that is artificially recharged into groundwater should not be lower than the standard of drinking water, or it will decrease the local groundwater quality.

In addition to establishing a protected area around water sources, the environmental protection, health, and water supply authorities should monitor industrial and domestic wastewater discharges, wastewater irrigation, and cases of infection and accidental pollution. If water pollution occurs, it should be reported to the responsible body and to the water authorities so that they may take the necessary measures for protecting water sources.

Water quality should be examined according to the *Domestic Water Quality Testing Methods*. For urban piped supply systems, a water-quality laboratory must be set up, responsible for examining raw water, treated water, water ready for supply, and water in distribution networks. For large or medium-sized enterprises that have their own water supply systems, specialists within the organization should be given responsibility for their own water examination. For other units with independent water supply systems, the local government authority should appoint a testing unit to take the responsibility for water-quality examination, and the local health authority should take samples for water-quality tests.

For private water supply or rural piped supply systems, the quality should be examined by the local health department or the commune sanitary station.

For domestic water supplies, samples should be taken from places where water is frequently withdrawn, and the results of analyses should be comprehensive. For urban piped supply systems, one sample should be taken for every 20 000 people being served by the system. If the population served is more than 1 million, the number of samples may be fewer, but for a service population under 200 000, the number of samples should be more. A reasonable proportion of samples should be taken from the service connection, the end of the distribution network, the older part of the distribution network — anywhere the supply may become contaminated.

Sampling should be carried out at least twice a month at all sampling points, more often if possible. In general, bacteriological and physical criteria should be examined regularly; according to the local situation and requirements, chemical and toxicological criteria should be selectively examined. Sampling points and selective items of examination should be studied and chosen by the water-supply authority associated with the local health department.

For private supplies and piped supply systems in rural areas, sampling points, the number of samples, and items for examination should be decided by local authorities, and the results of examination should be submitted to the local health department.